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ASD-TR-61-625

THERMODYNAMIC DATA
on
OXYGEN AND NITROGEN

TECHNICAL DOCUMENTARY REPORT

No. ASD-TR-61-625

September 1961

Directorate of Materials and Processes
Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

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Project 1 (1-3048), Task 304802

(Prepared under Contract No. AF 33(616)-8287
by Air Products and Chemicals, Inc., Allentown,
Pennsylvania; Jerome Brewer, author)

FOREWORD

This report was prepared by Air Products and Chemicals, Inc., under USAF Contract No. AF 33 (616)-8287. This contract was initiated under Project No. 1 (1-3048), "Aviation Fuels", Task No. 304802, "High Energy Fuels". The work was administered under the direction of the Directorate of Materials and Processes, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, with Messrs. James H. L. Lawler and Perie R. Pitts, Jr. of ASD acting as Project Engineers.

This report covers work conducted from May 1961 to September 1961.

The work covered in this report was conducted by Dr. Jerome Brewer, Project Leader, supervised by Dr. J. M. Geist, Associate Director, and directed by Dr. Clyde McKinley, Director, Research and Development Department. Dr. Leonard Wenzel of Lehigh University, and Mr. J. A. Carlson, Jr., Manager of Advanced Projects, participated in the review of the work performed. Special thanks are due Mr. G. M. Gigliotti, for his technical editorship, and Miss Fay A. Jones, for preparing the manuscript.

ABSTRACT

The following data, which were compiled from published literature, are presented graphically as a function of temperature and pressure:

Viscosity of Nitrogen, Viscosity of Oxygen, Viscosity of Air, Viscosity of Saturated Liquid (Oxygen, Nitrogen, and Mixtures), Vapor-Liquid Equilibrium Ratios: Oxygen-Nitrogen System, Dew Points: Oxygen-Nitrogen System, Bubble Points: Oxygen-Nitrogen System, Thermal Conductivity of Nitrogen, Thermal Conductivity of Oxygen, Thermal Conductivity of Saturated Liquefied Nitrogen and Oxygen, Density of Oxygen, Density of Nitrogen, Prandtl Number of Nitrogen, and Prandtl Number of Oxygen.

For each of the above properties a discussion of their critical evaluation was made. Two complete sets of curves were presented, one set with experimental and correlative data points and one set without data points. A complete bibliography of the sources used for each property are given as well as a master bibliography which include all sources consulted or related to the subject. Tables of tabulated values of the properties used to construct the various graphs are presented.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER

Marc P. Dunnam

MARC P. DUNNAM
Chief, Fuels & Lubricants Branch
Nonmetallic Materials Laboratory
Directorate of Materials & Processes

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I. INTRODUCTION

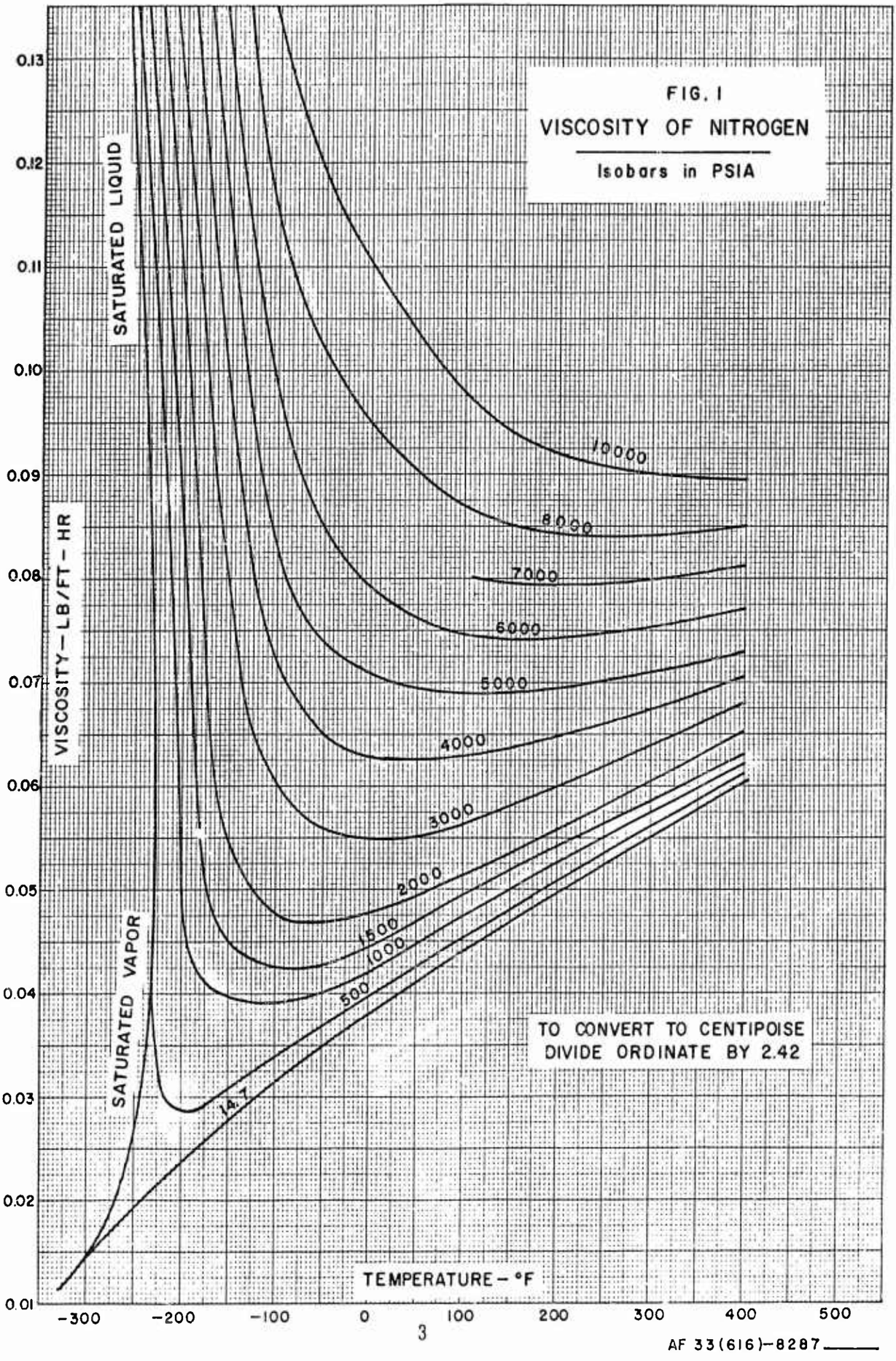
This report presents in graphical and tabular form thermodynamic data on oxygen and nitrogen. The data include viscosity, vapor dew point, liquid bubble points, vapor-liquid equilibrium ratios, thermal conductivity, density, and Prandtl Number of the two elements, as well as mixtures thereof, in the pressure range of 10 psia to 10,000 psia and the temperature range of -330°F to 500°F.

On the following pages may be found the complete series of charts, without data points or references, presented for easy reference. In subsequent sections may be found the selected bibliography, discussion of the data, and the specific charts showing data points and their source. Also included in this report are a complete and up-to-date bibliography, and a tabulation of the data used in constructing the charts.

Manuscript released by the author September 1961 for publication as an ASD Technical Documentary Report.

II. SUMMARY

The thermodynamic properties of nitrogen and oxygen (including some data on their mixtures) such as viscosity, vapor-liquid equilibrium ratios, dew points, bubble points, thermal conductivity, density of gas and liquid, and Prandtl Number, are presented as a function of temperature and pressure in Figures 1 to 19 inclusive. These data are based on a critical evaluation of the published literature up to July 1961.



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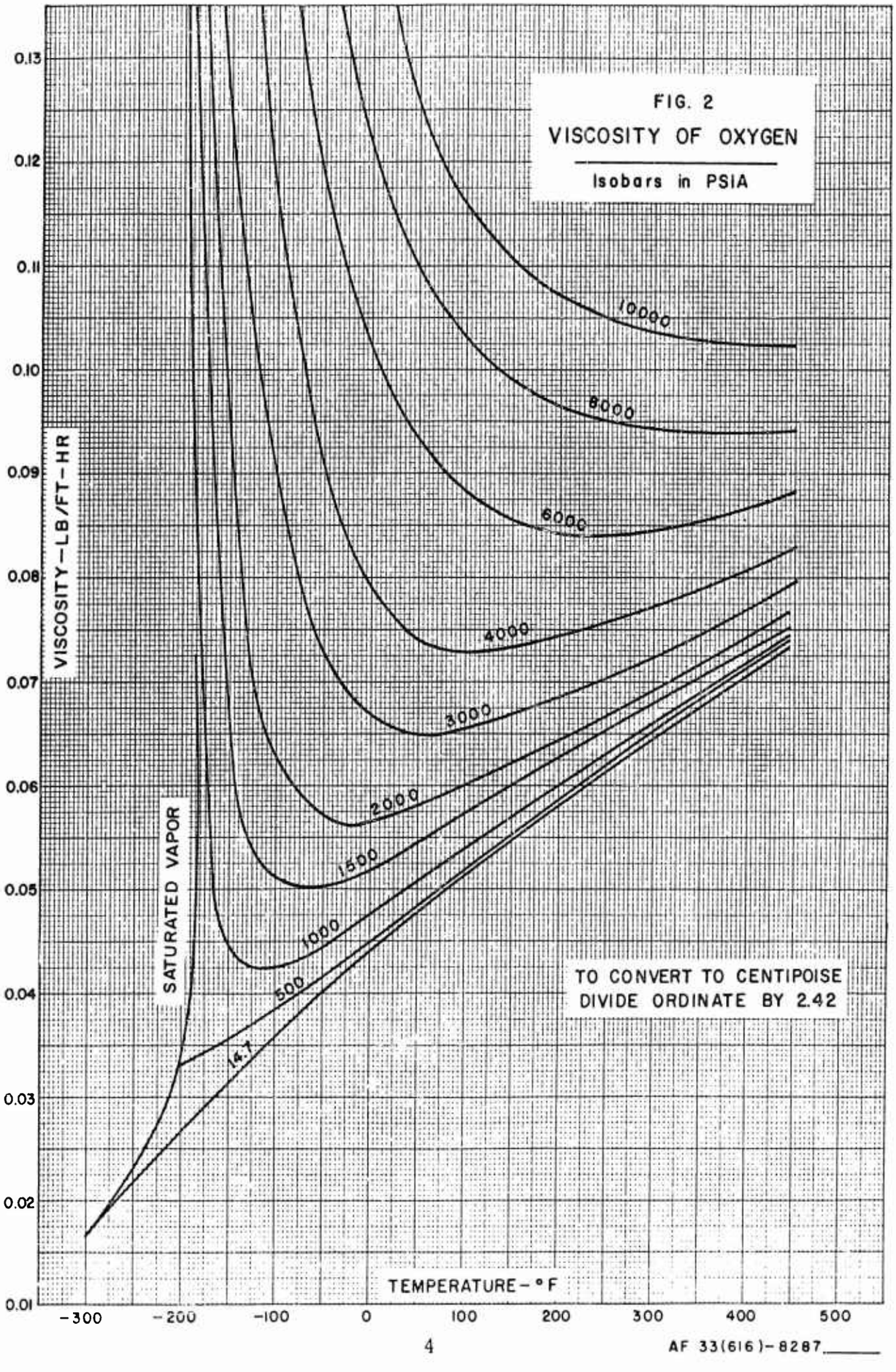

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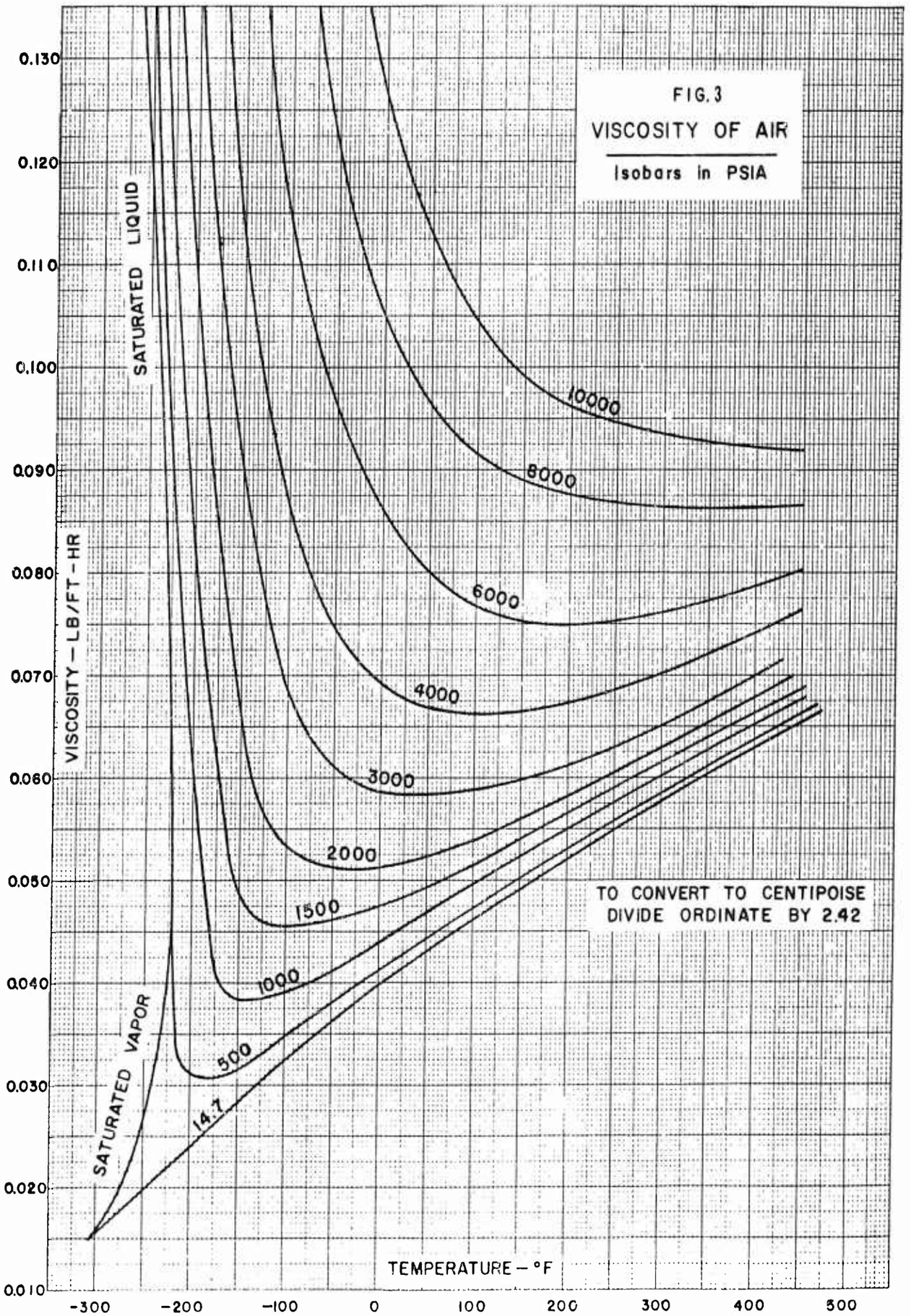

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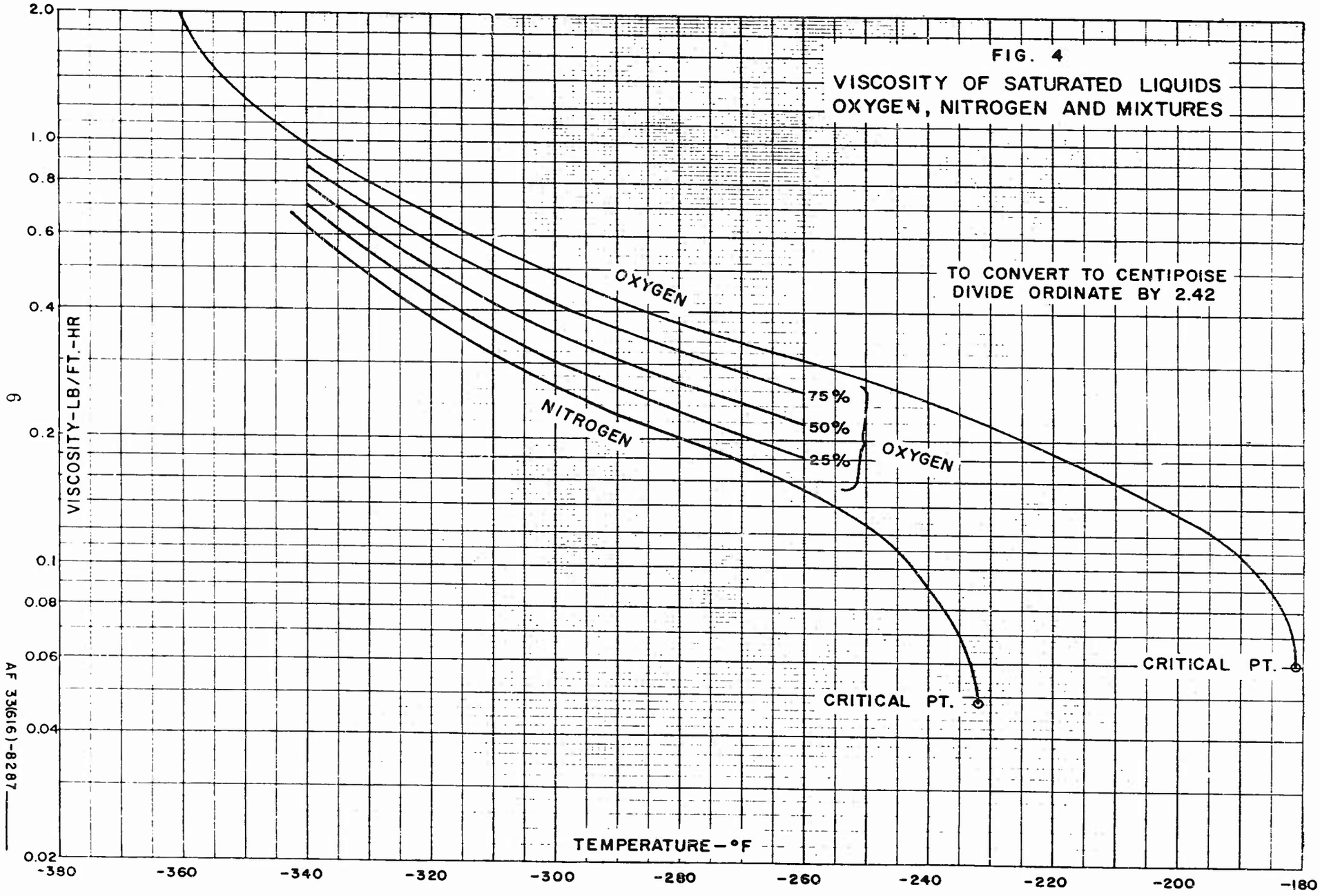

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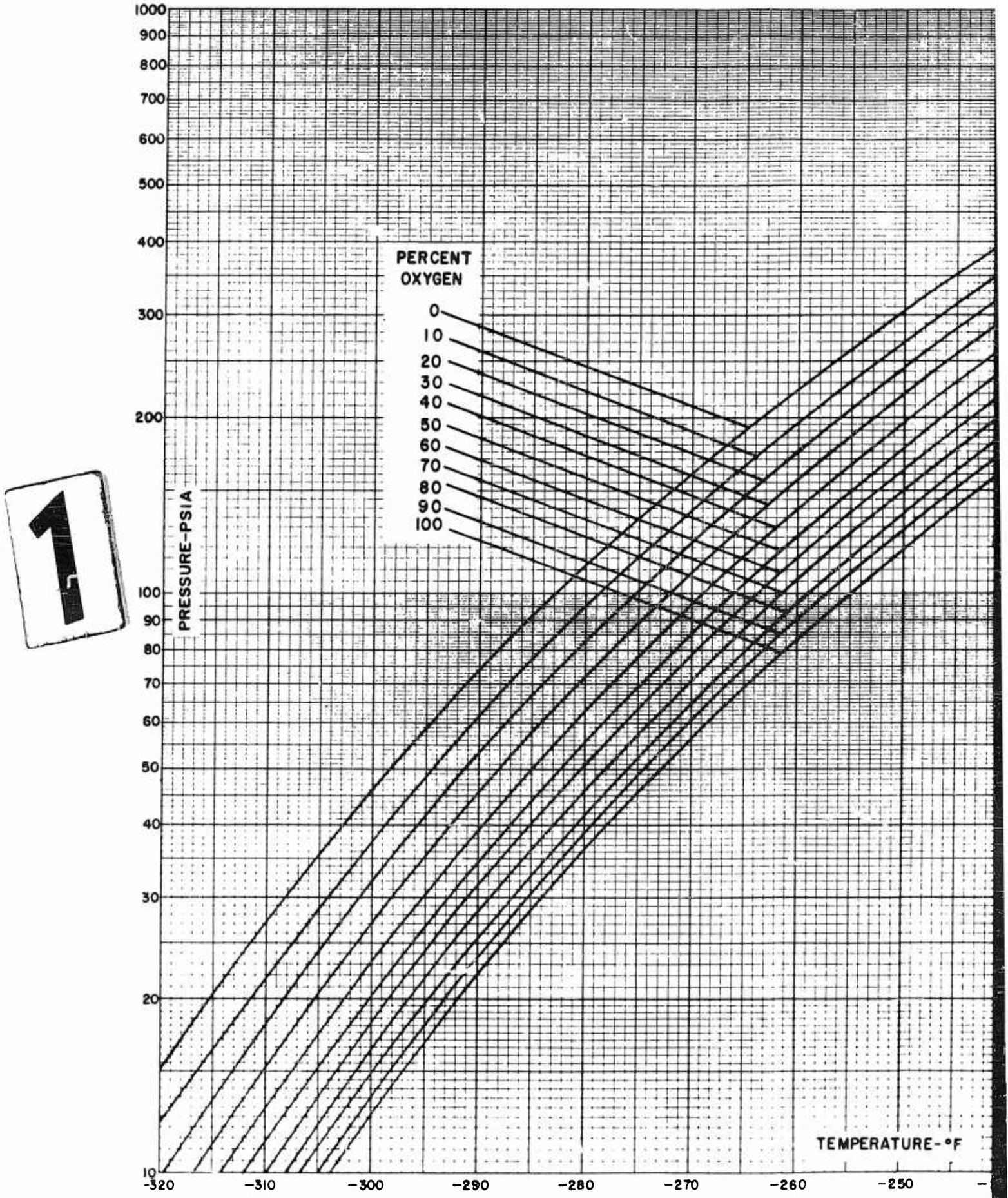
PERCENT OXYGEN
0
10
20
30
40
50
60
70
80
90
100
PRESSURE-PSIA
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
-320
-310
-300
-290
-280
-270
-260
-250
TEMPERATURE-°F

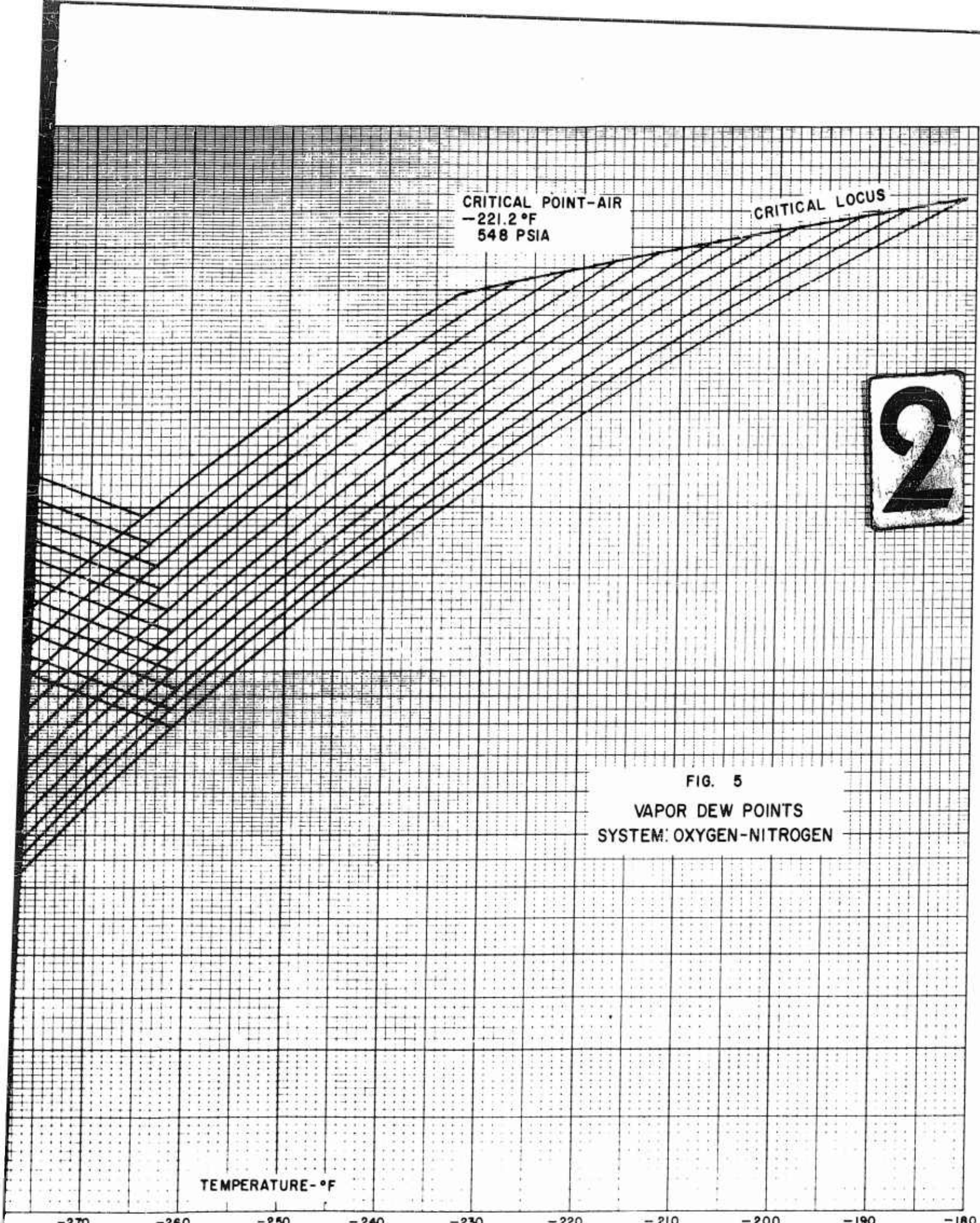

FIG. 5

VAPOR DEW POINTS
SYSTEM: OXYGEN-NITROGEN

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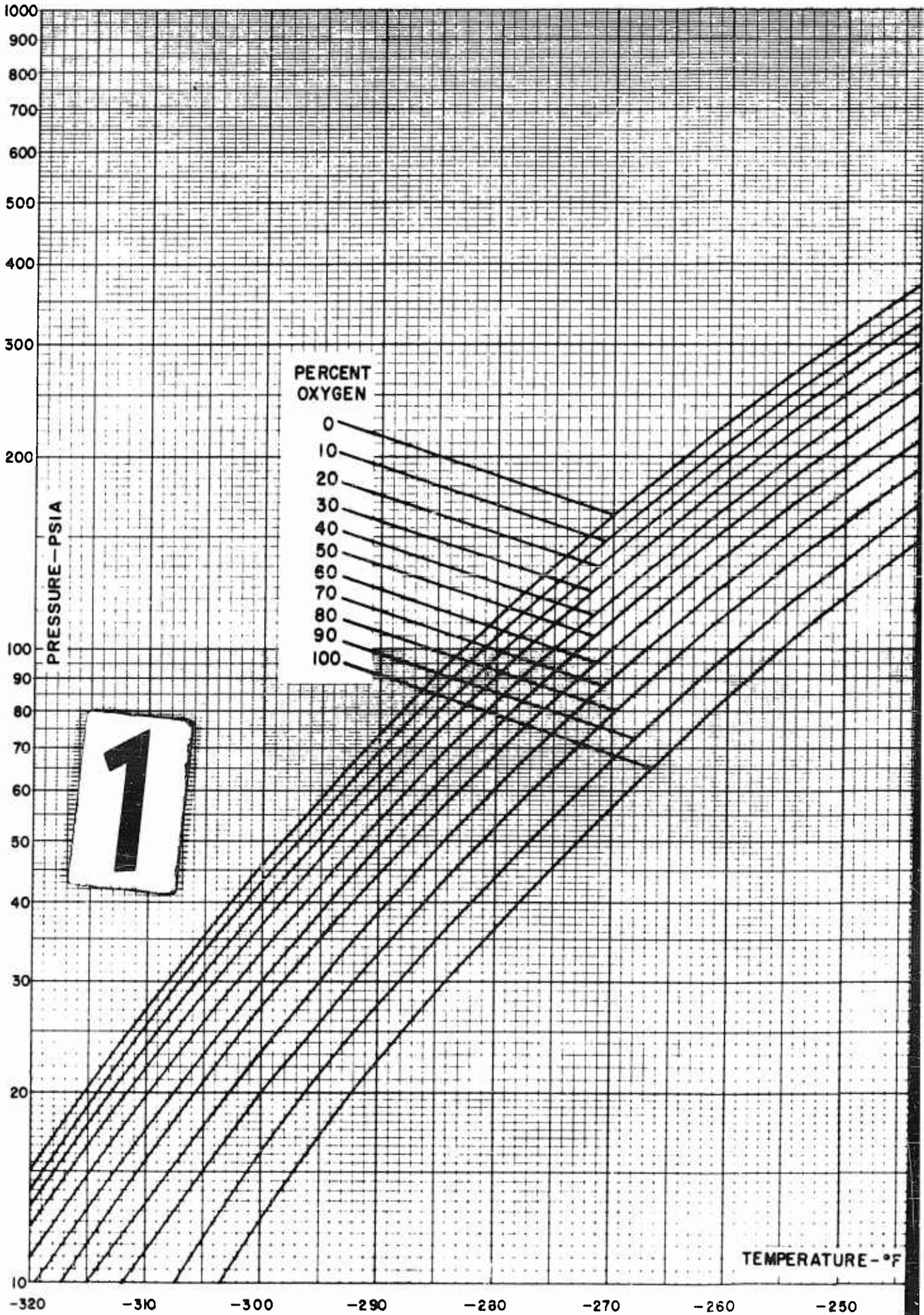
PRESSURE—PSIA
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
PERCENT OXYGEN
0
10
20
30
40
50
60
70
80
90
100
1
TEMPERATURE—°F
-320
-310
-300
-290
-280
-270
-260
-250

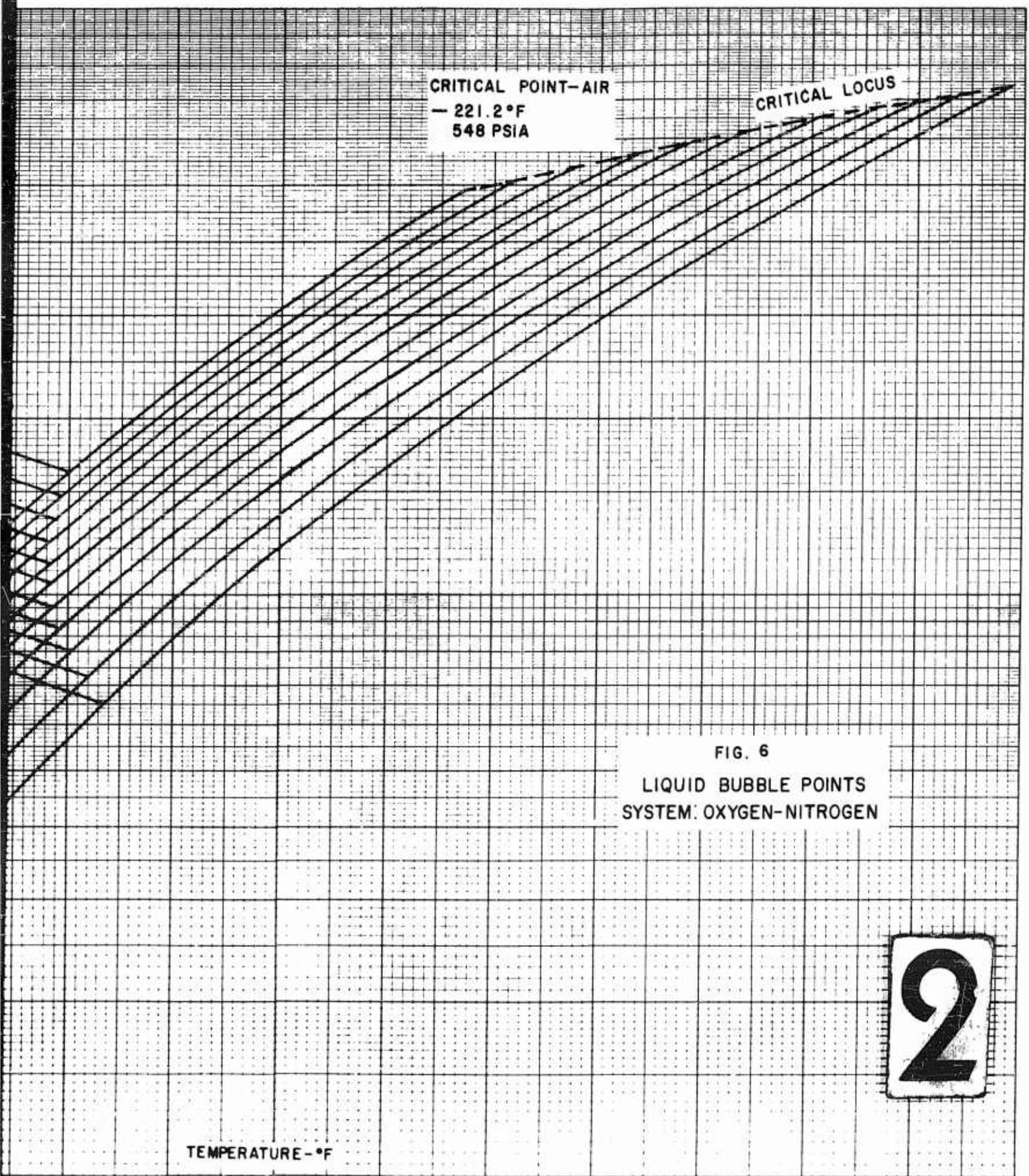

FIG. 6

LIQUID BUBBLE POINTS

SYSTEM: OXYGEN-NITROGEN

2

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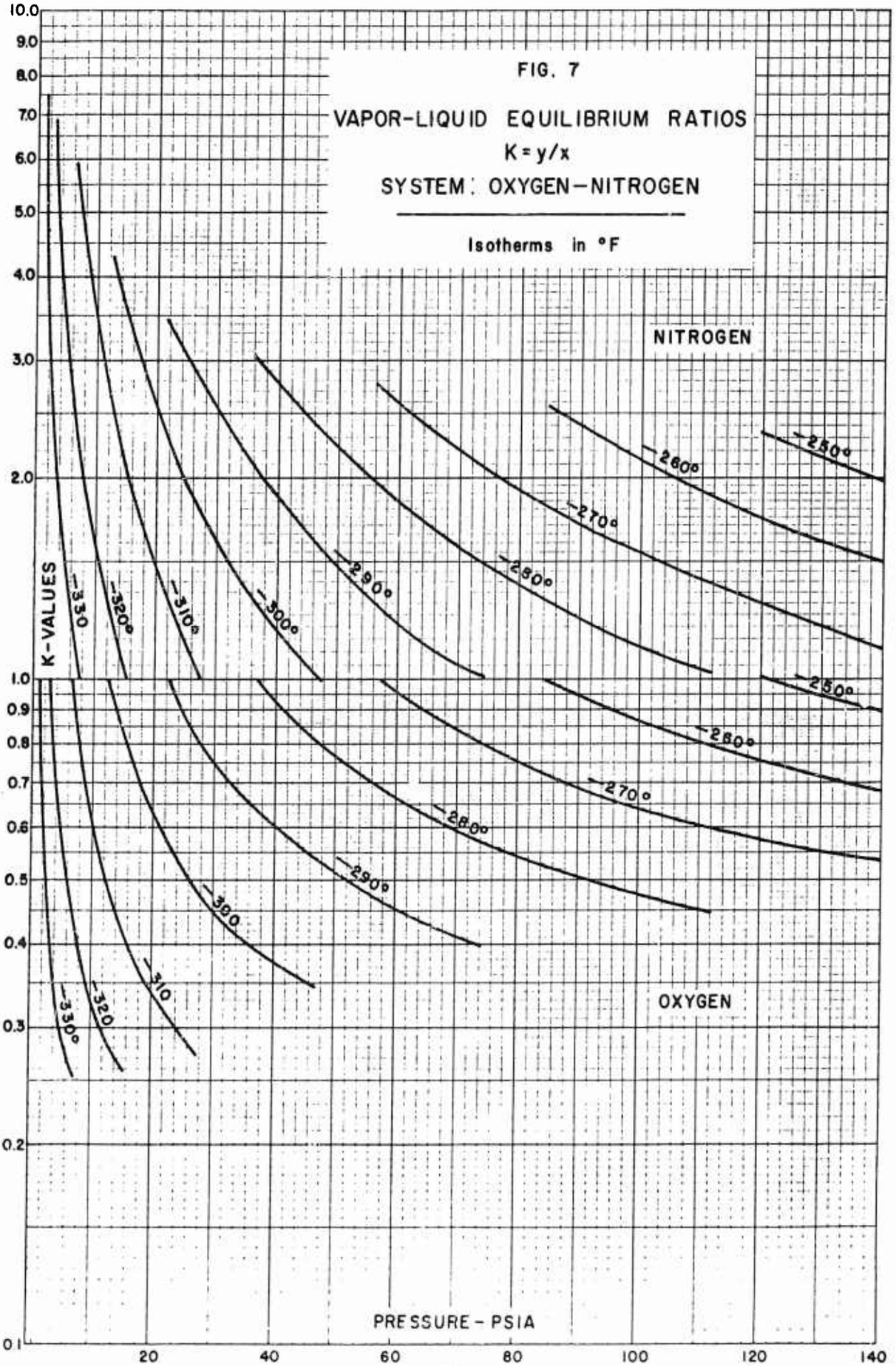

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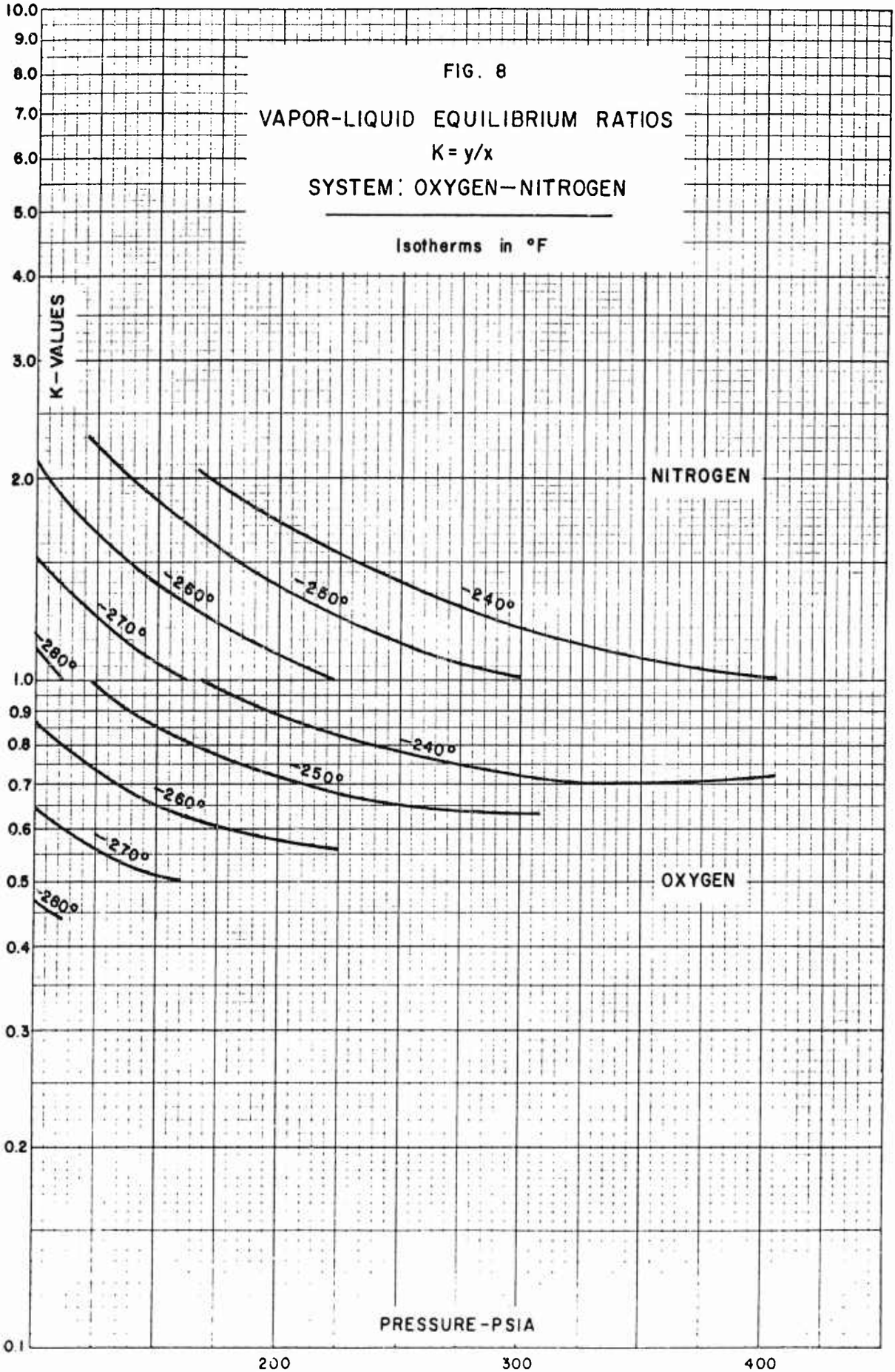

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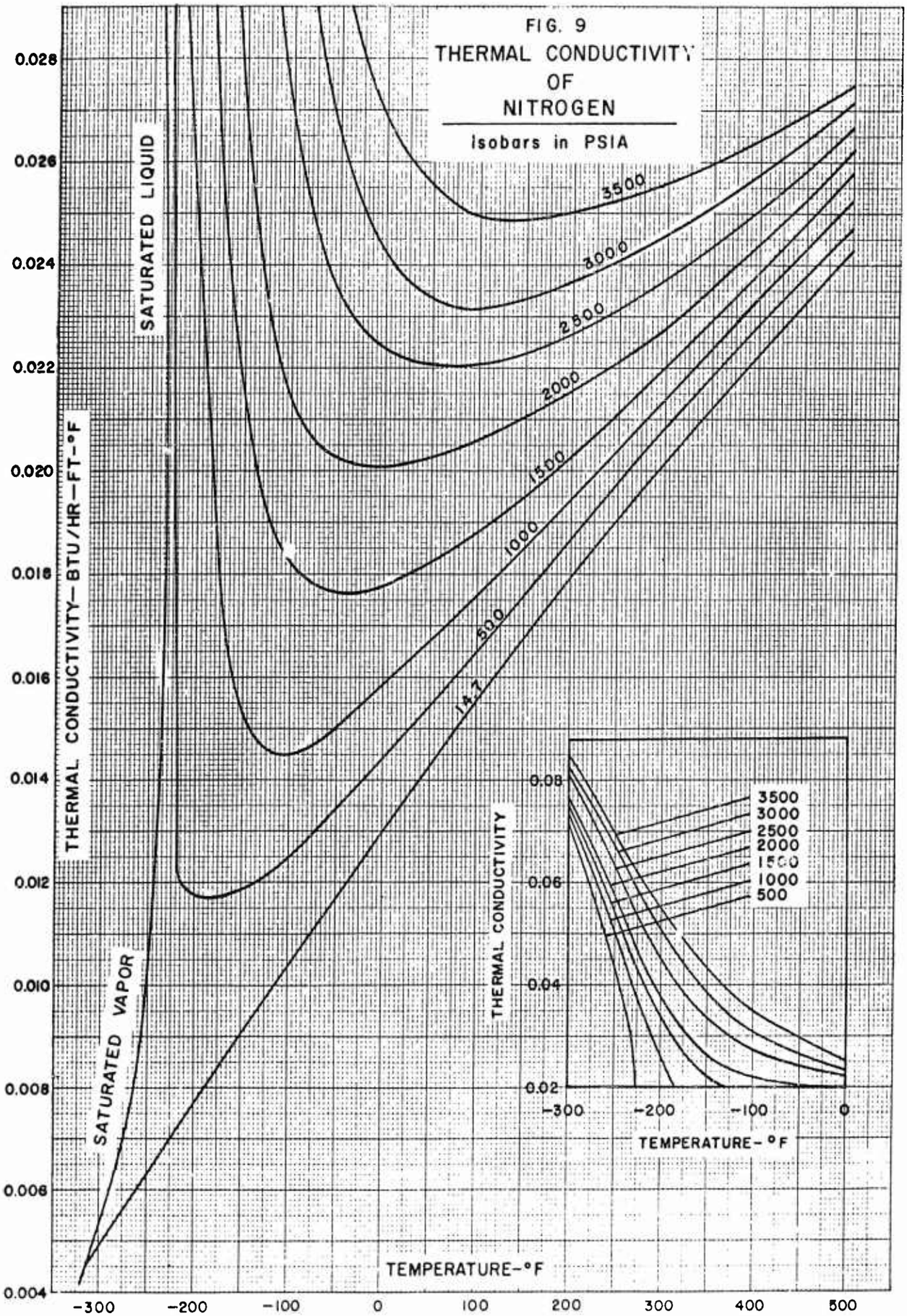

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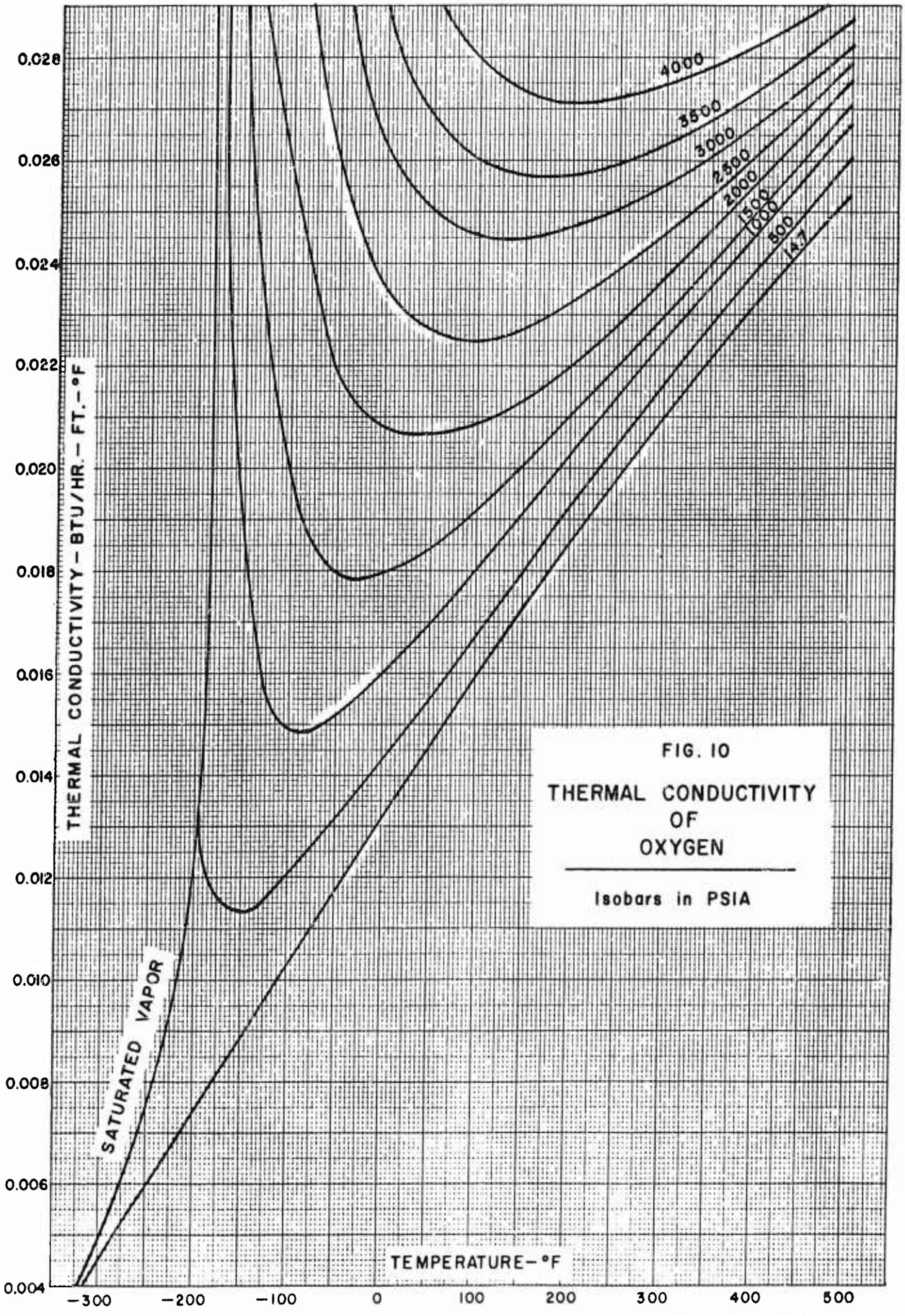

FIG. 10

THERMAL CONDUCTIVITY OF OXYGEN

Isobars in PSIA

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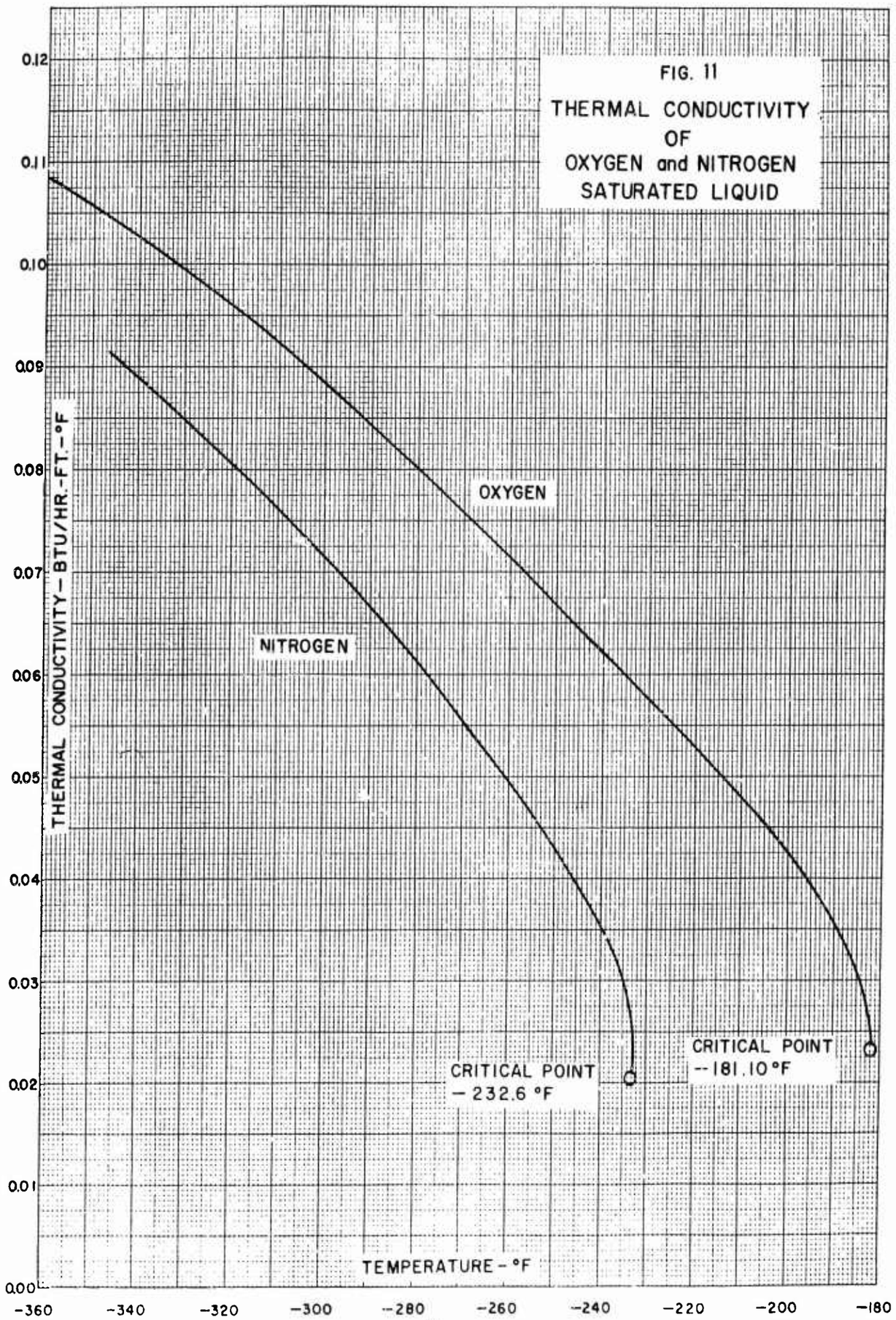

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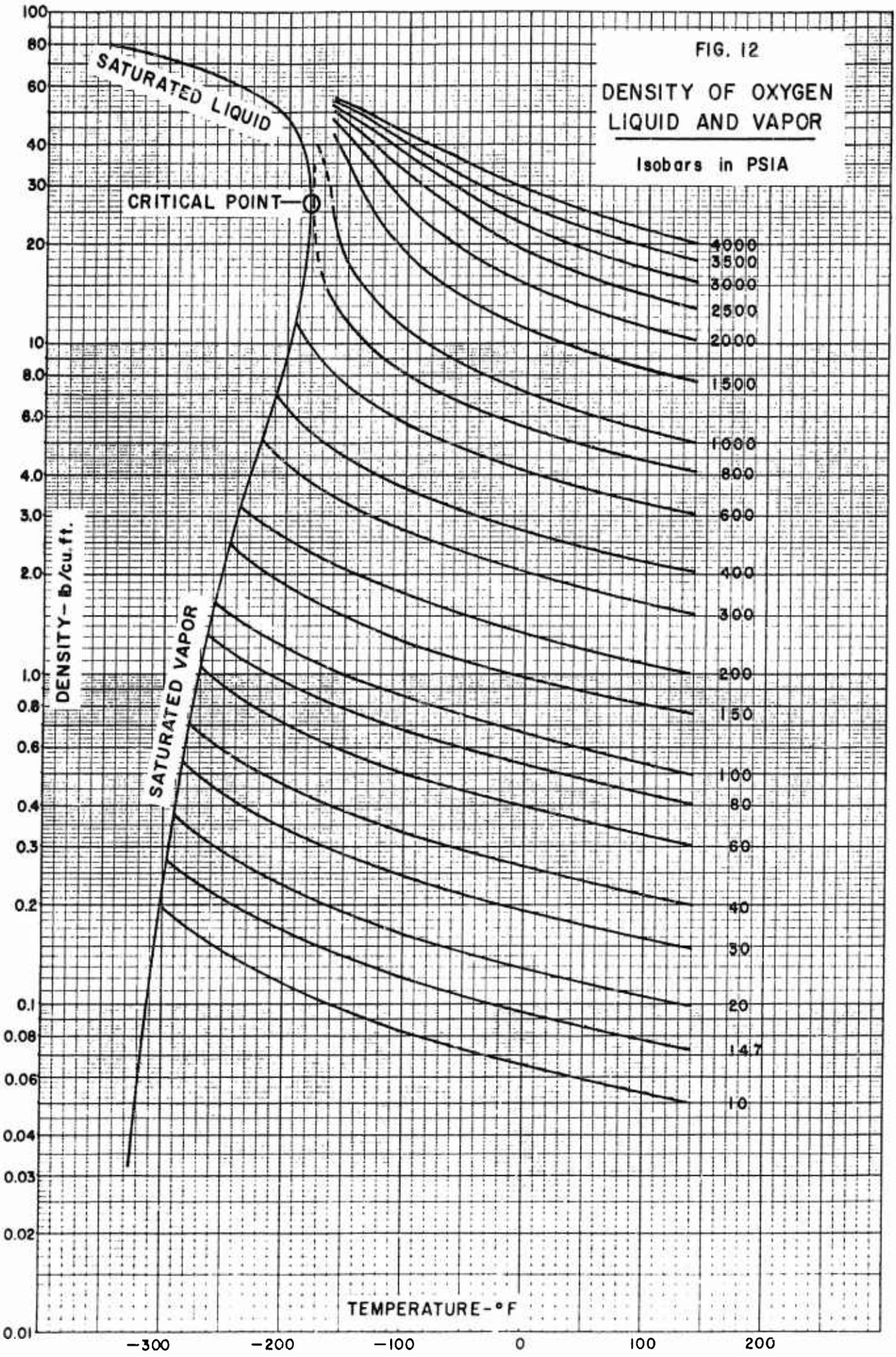

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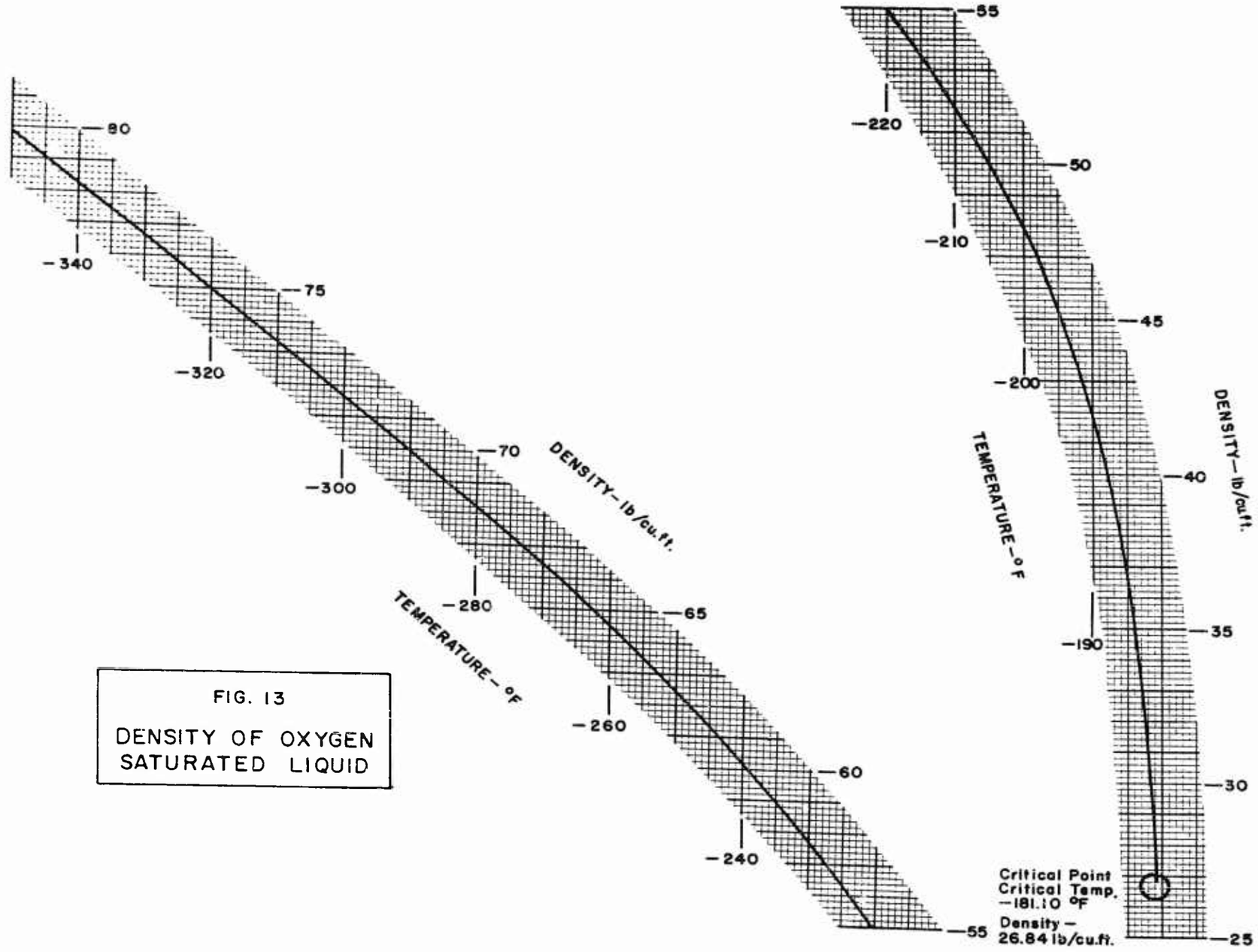
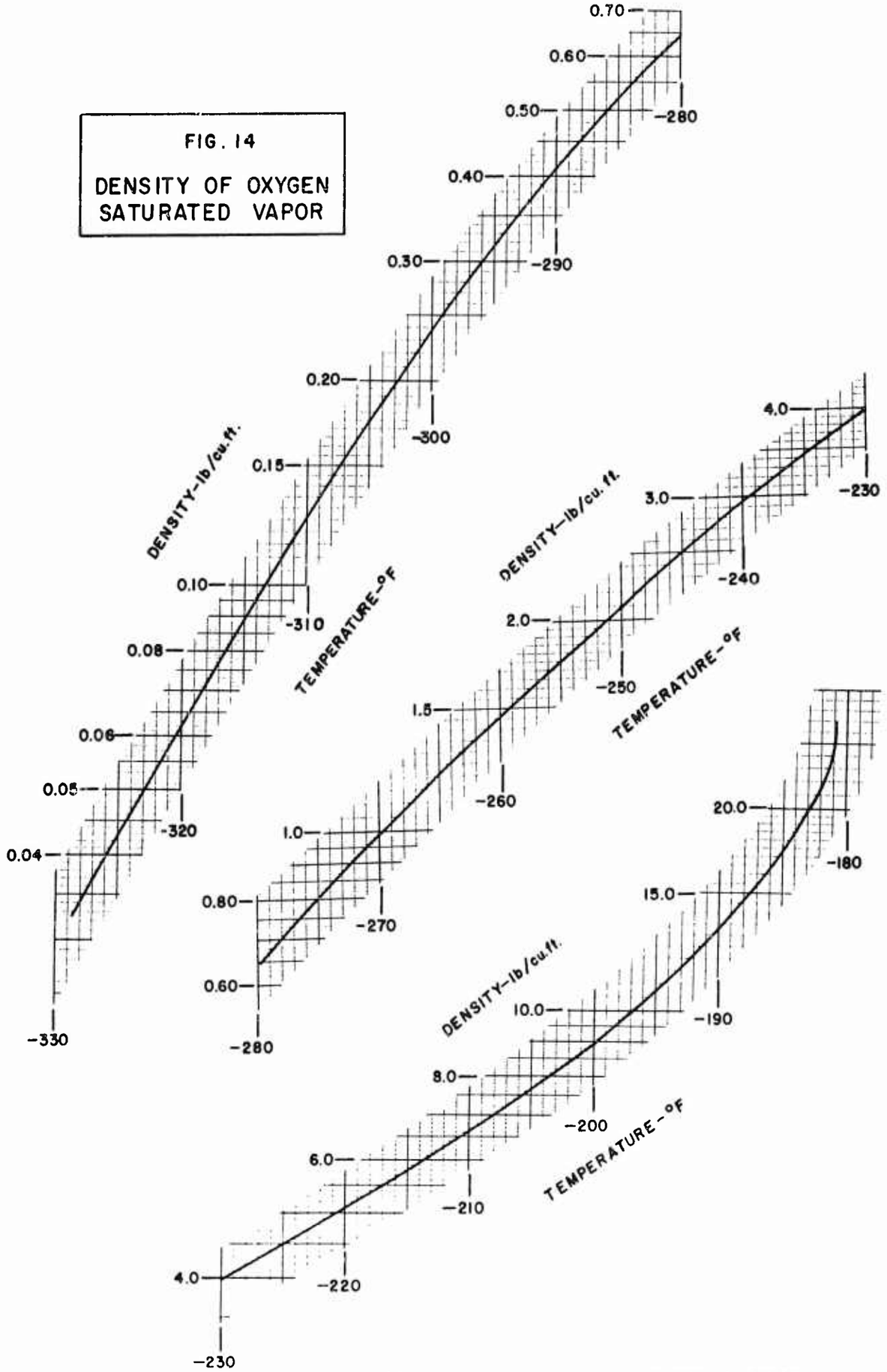


FIG. 13

DENSITY OF OXYGEN
SATURATED LIQUID

FIG. 14

DENSITY OF OXYGEN SATURATED VAPOR



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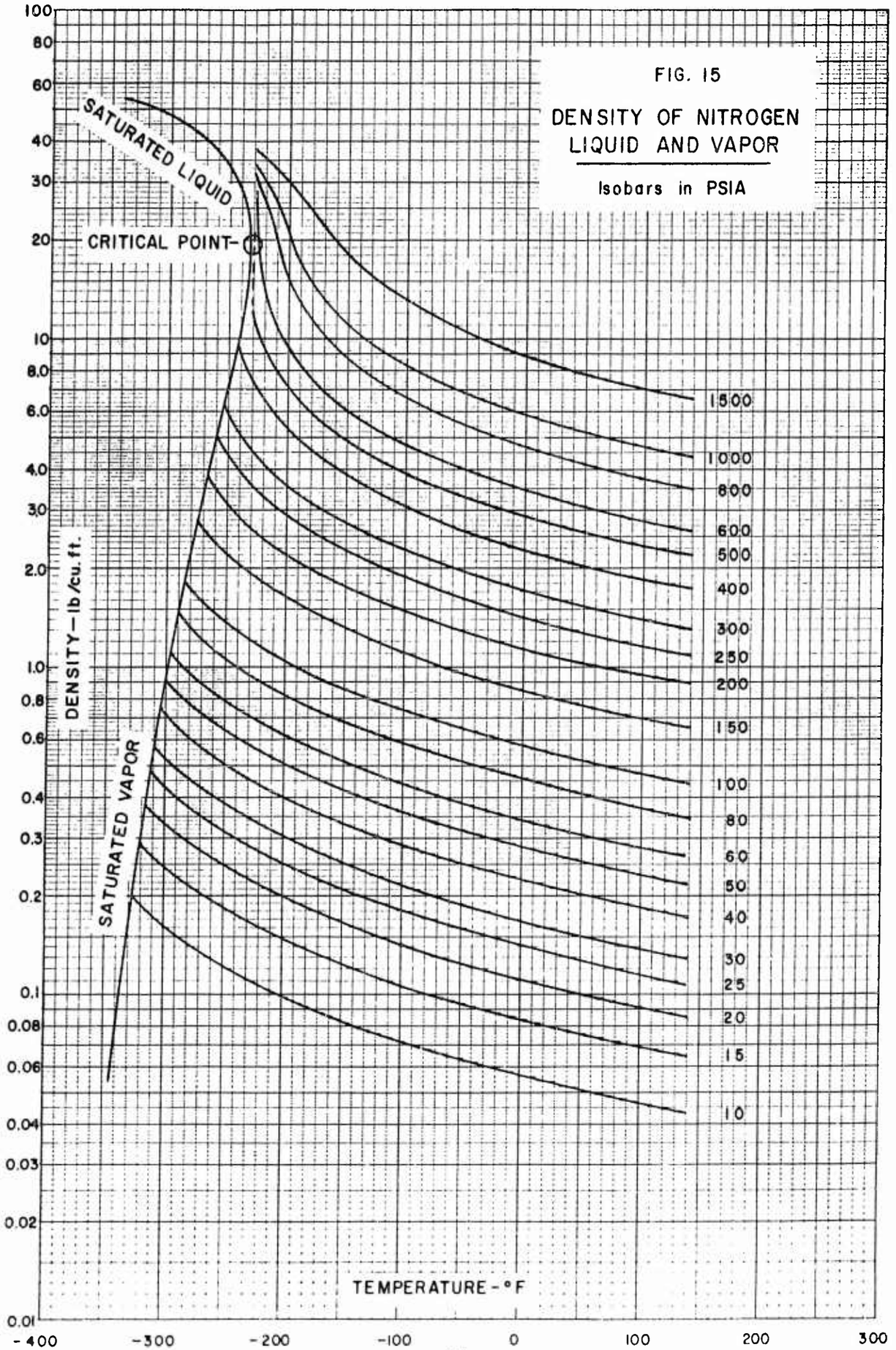

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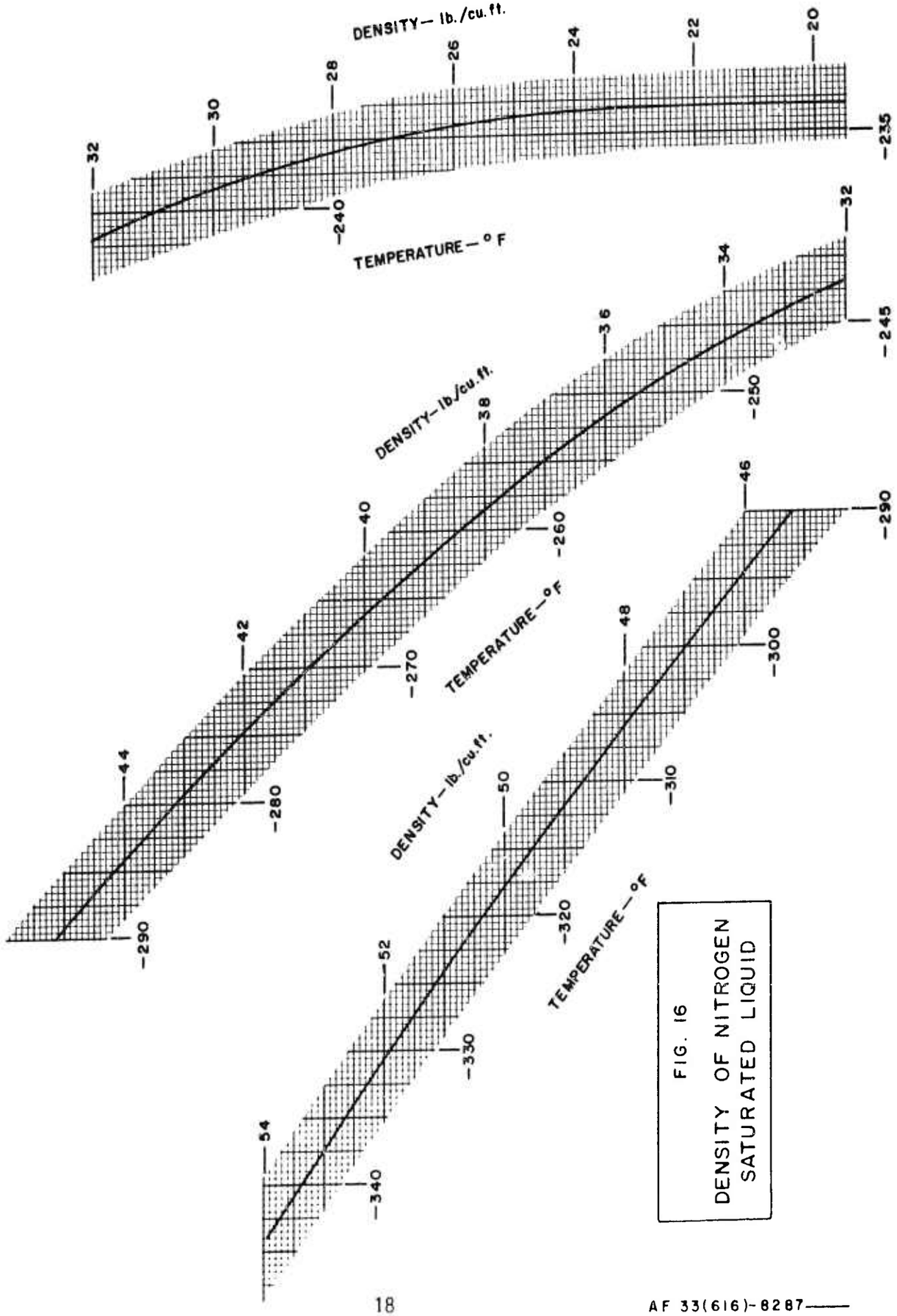


FIG. 16
DENSITY OF NITROGEN
SATURATED LIQUID

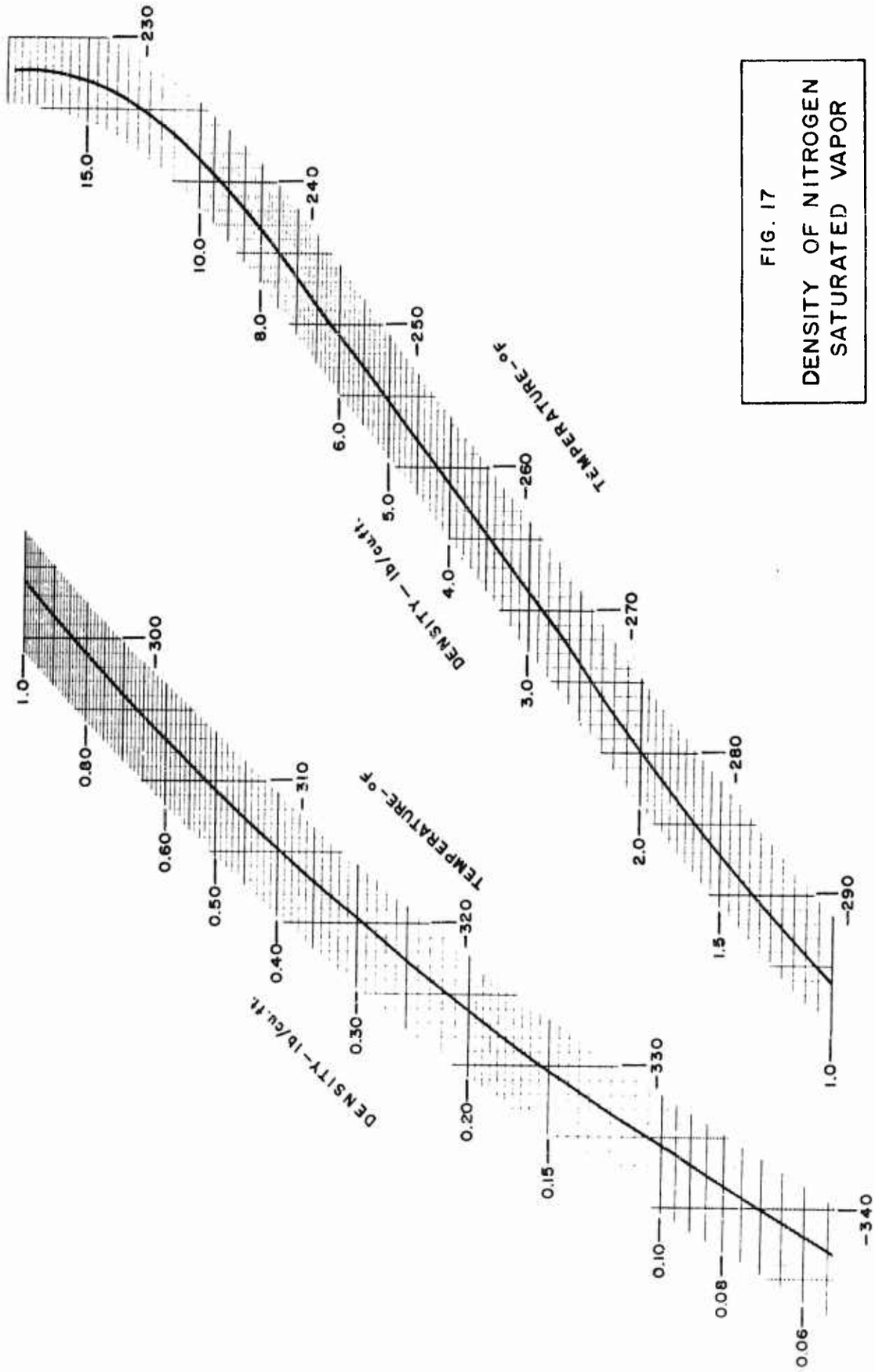
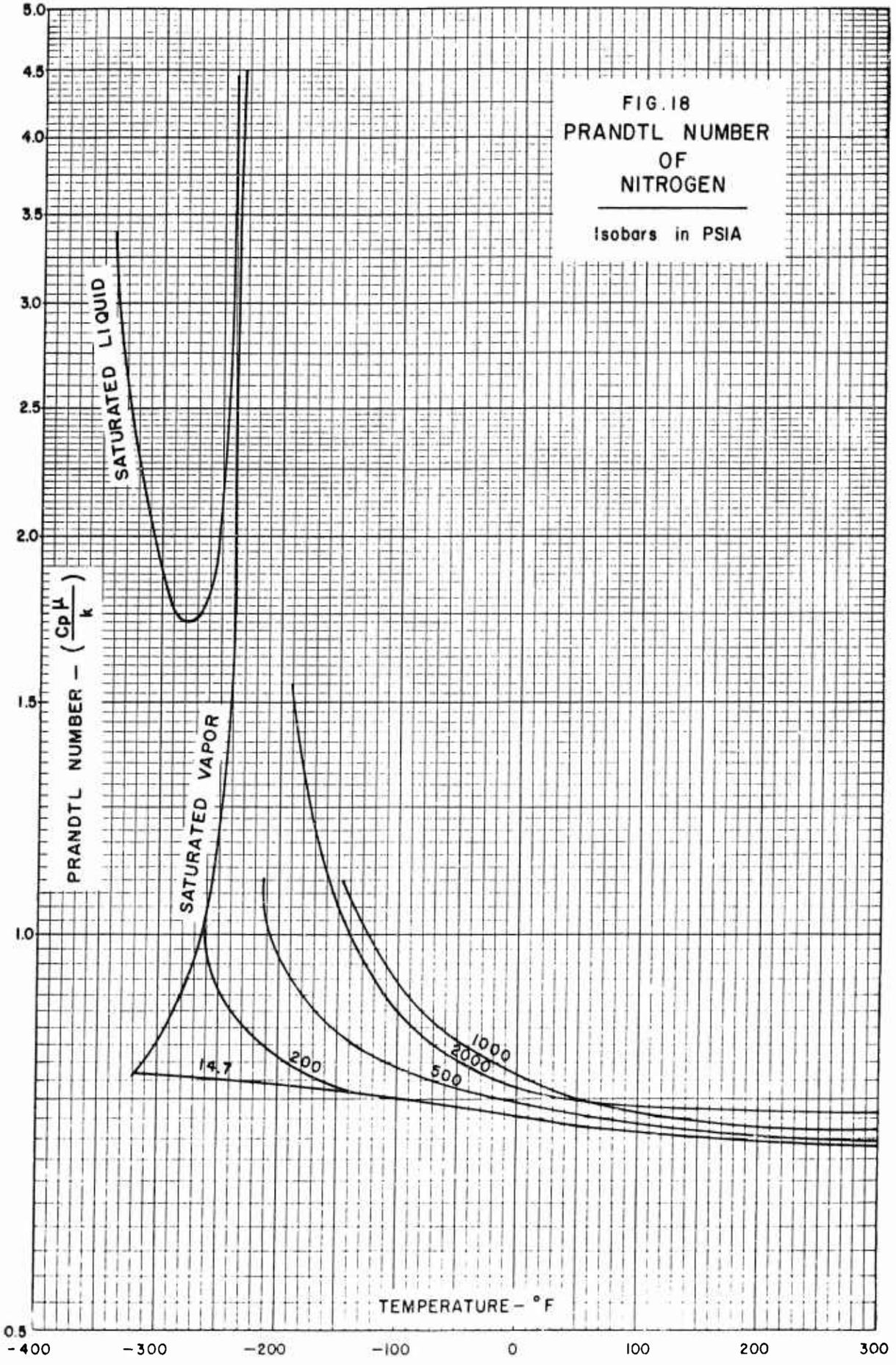


FIG. 17
DENSITY OF NITROGEN
SATURATED VAPOR



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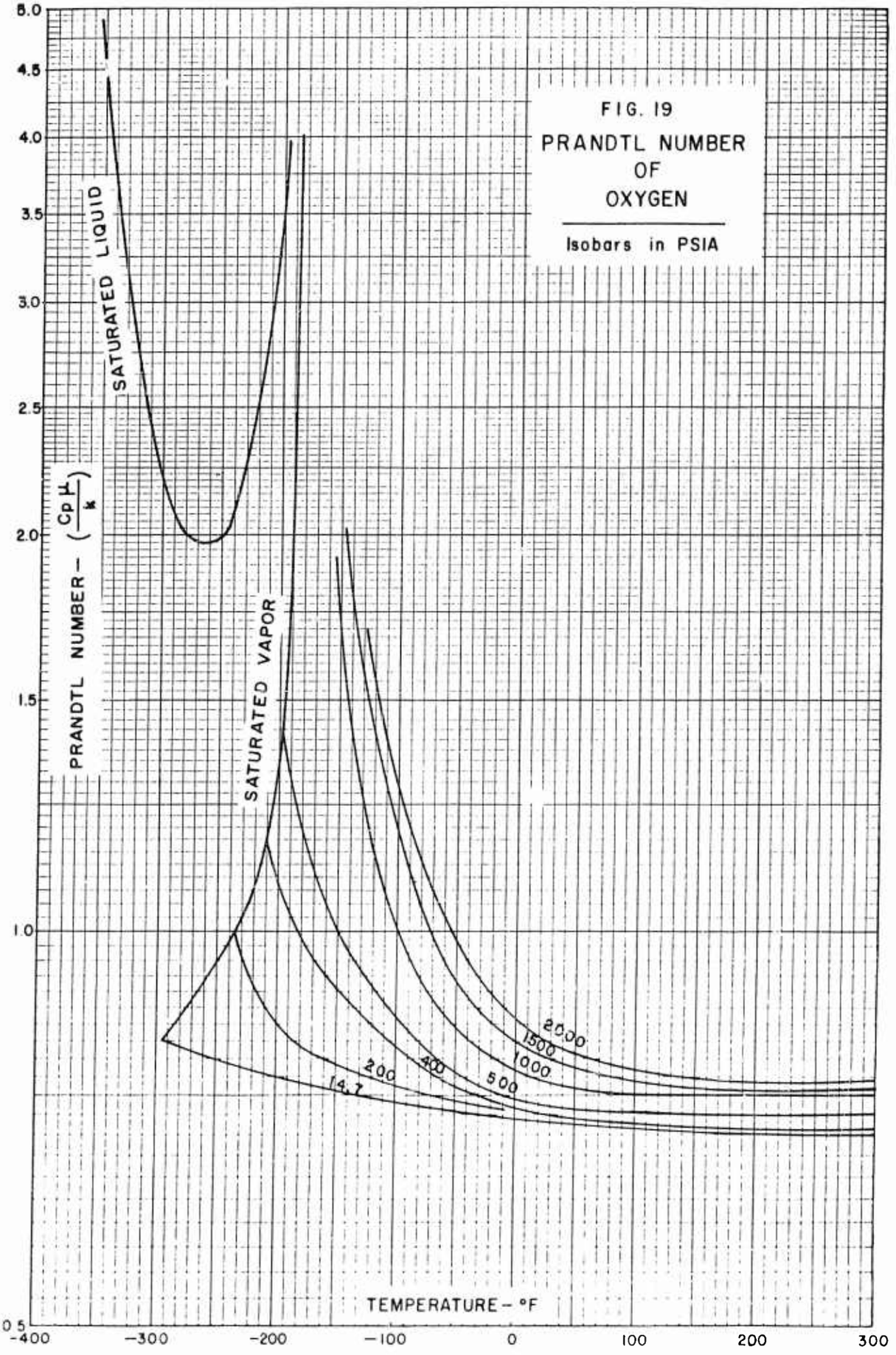


FIG. 19
PRANDTL NUMBER
OF
OXYGEN
Isobars in PSIA
PRANDTL NUMBER – $\left(\frac{Cp\,\mu}{k}\right)$
SATURATED LIQUID
SATURATED VAPOR
2000
1500
1000
500
400
200
14.7
TEMPERATURE – °F
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
-400
-300
-200
-100
0
100
200
300

III. DISCUSSION AND CRITICAL EVALUATION

In the following subsection is presented a discussion of the data and an evaluation of the agreement among the several investigators whose work was selected for inclusion in this report. The sources of the data pertaining to each chart are listed and the experimental and analytical procedure used by each investigator is described and the accuracy obtained is discussed. Following each discussion is the subject chart with the data points plotted. The data points used in the plots may be found in tables in the Appendix.

A. Viscosity of Nitrogen

Sources of Data:

1. Baron, J.D., J.G. Roof, and E.W. Wells, "Viscosity of Nitrogen, Methane, Ethane, and Propane at Evelated Temperatures and Pressure", Journ. Chem. Eng. Data 4, 283-288 (1959).

2. Brebach, W.J. and G. Thodos, "Viscosity-Reduced State Correlation for Diatomic Gases", Ind. Eng. Chem. 50, 1095-100 (1958).

3. Johnston, H.L. and K.E. McCloskey, "Viscosities of Several Common Gases between 90°K and Room Temperature", Journ. Phys. Chem. 44, 1038 (1940).

4. Kestin, J. and W. Leidenfrost, "Absolute Determination of the Viscosity of Eleven Gases Over a Range of Pressures", Physica 25, 1033-62 (1959).

5. Michels, A. and R.O. Gibson, "The Measurement of the Viscosity of Gases at High Pressures -- The Viscosity of Nitrogen at 1000 Atms.", Proc. Roy. Soc. (London) A134, 288-307 (1931).

6. Ross, J.F. and G.M. Brown, "Viscosities of Gases at High Pressures", Ind. Eng. Chem. 49, 2026-33 (1957).

Figure 20 shows the data points obtained from the various literature sources. The atmospheric pressure line is obtained at lower temperatures from Johnston and McCloskey (3), while at temperatures above 100°F the data of Baron, Roof, and Wells (1) were used. Data on viscosity of compressed N_2 were available at temperatures from -60 to +275°F and pressures up to 10,000 psi (1, 4, 5, 6). These data were consistent except for the highest pressure data of Michels and Gibson (5), and were also used as primary information sources. At temperatures below -60°F the viscosity of nitrogen for the isobars from 500 to 10,000 psi were obtained through correlations of Ross and Brown (6) and of Brebach and Thodos (2). These correlations agreed within about $\pm$ 10% in the area where they were both usable. Brebach and Thodos (2) also gave information allowing the saturation boundary and the viscosity of sub-critical temperatures to be obtained.

Baron, Roof, and Wells (1), used a transpiration viscometer in their measurements. Gas in a closed glass loop was removed through a capillary section by the fall of a mercury pellet in the opposite leg of the loop. The glass loop was enclosed in a thermostatic pressure vessel and the pressure within the loop balanced against that in the vessel. The position of the mercury pellet was sensed by tungsten contacts, and its size was adjusted to give gas Reynolds numbers in the capillary well below 2000. The rate of fall of the mercury pellet was kept independent of surface tension effects by scrupulously cleaning the glassware and by careful design of the tungsten contacts. Temperature was controlled to 0.05°F and pressure to 1 psi. The data were internally consistent to within $\pm$ 1%. The only external comparison that can be made is against the data of Michels and Gibson (5) extrapolated to 175°F. Differences are generally less than 3%, with the Baron data giving lower values of viscosity at low pressure and higher values at pressures above 2000 psi. Michels and Gibson (5) also used a transpiration method, and obtained data at about the same accuracy as that of Baron (1).

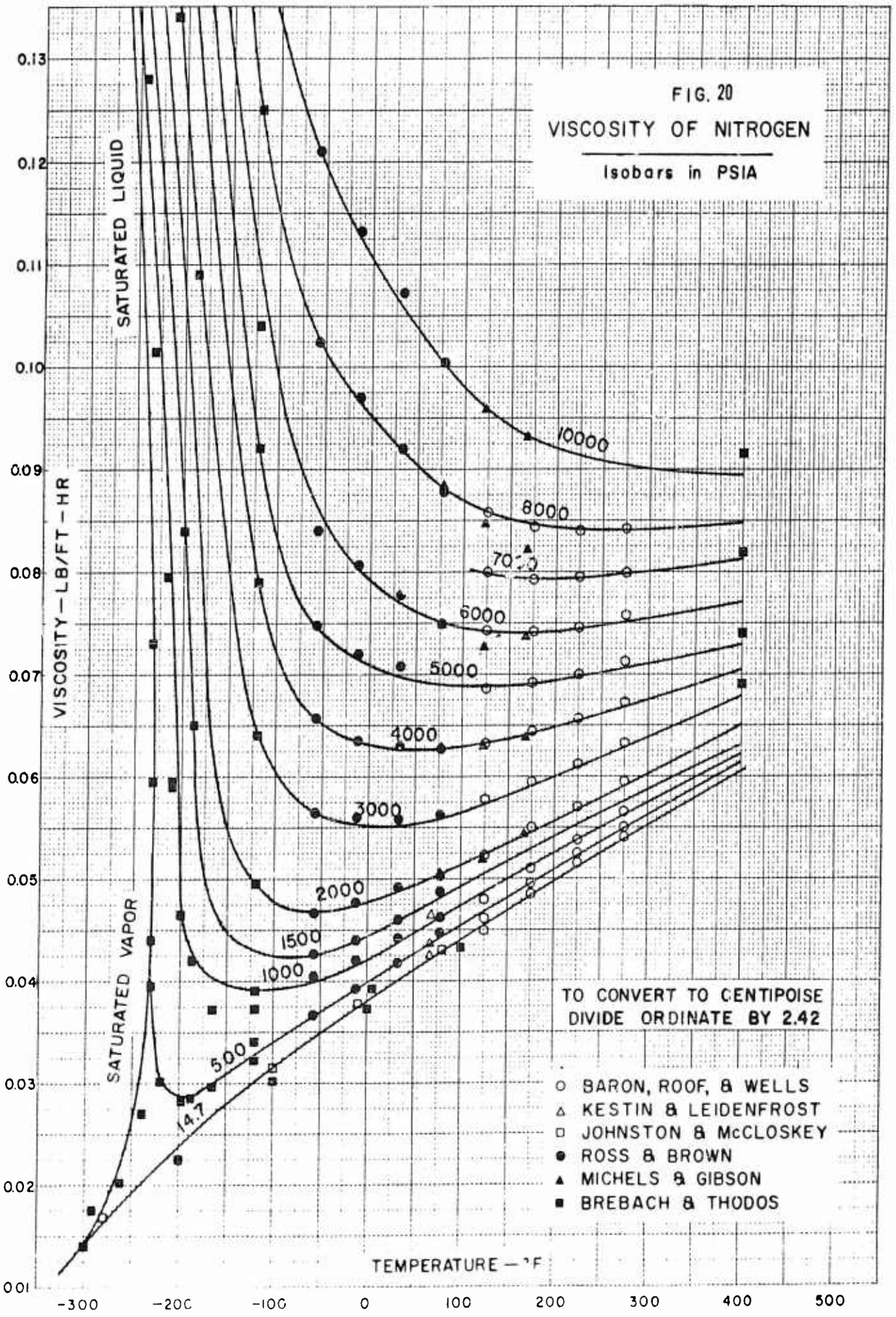
Ross and Brown (6) also used a transpiration viscosimeter, in which gas flow was driven by a pair of instrument bellows attached to the two ends of the capillary tube. The use of bellows allowed viscosity to be determined at temperatures above -50°C. Proper interpretations of results required extensive calibration and connections but comparisons with the data of Michels and Gibson (5) and internal comparisons lead to an estimated accuracy of $\pm$ 1%.

At temperatures below -60°F, primary reliance was placed upon the correlation of Brebach and Thodos (2). They found that residual viscosity ($\mu - \mu^*$) was a function of the fluid density alone. The symbol μ^* represents the viscosity of the fluid at the desired temperature but at atmospheric pressure. Data for nitrogen gas at all pressures and for nitrogen liquid could be correlated in this way. From a knowledge of the density of nitrogen obtained from the literature, the viscosity of nitrogen was calculated for all desired values of temperature and pressure. The results have been compared with 198 data points for nitrogen obtained from experiment with a root mean square deviation of 1%.

The agreement found between the several experimenters leads to high confidence in the data for viscosity above -60°F. At pressures below 8000 psi and temperatures above -60°F the data should be accurate within $\pm$2%. For temperatures below -100°F and for pressures higher than 1 atmosphere the

results are less reliable, but probably within $\pm$ 5%. In part of this temperature range the viscosity isobars became almost vertical as the temperature is lowered and these regions of highly negative slope are in greatest doubt. An accuracy of $\pm$ 10% is expected.

The tabulated data are given in Table I.



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B. Viscosity of Gaseous Oxygen

Sources of Data:

1. Brebach, W.J. and G. Thodos, "Viscosity-Reduced State Correlation for Diatomic Gases", Ind. Eng. Chem. 50, 1095-100 (1958).

2. Glaser, F and F. Gebhardt, "Viscositatsmessungen an Gasen und Dampfen im Hochdruckgebeit und bei hohen Temperaturen", Chem-Ing-Tech 31, 743 (1959).

3. Hilsenrath, J. and Y.S. Touloukian, "The Viscosity, Thermal Conductivity, and Prandtl Number for Air, Oxygen, Nitrogen, Nitric Oxide, Hydrogen, Carbon Monoxide, Carbon Dioxide, Water, Helium, and Argon", Trans. ASME 76, 967-85 (1954).

4. Johnston, H.L. and K.E. McCloskey, "Viscosities of Several Common Gases between 90°K and Room Temperature", J. Phys. Chem. 44 1038 (1940).

5. Kestin, J. and W. Leidenfrost, "Absolute Determination of the Viscosity of Eleven Gases over a Range of Pressures", Physica 25, 1033-62 (1959).

6. Kiyama, R. and T. Makita, "The Viscosity of Carbon Dioxide, Ammonia, Acetylene, Argon, and Oxygen Under High Pressures", Rev. Phys. Chem. (Japan) 22, 49 (1952).

7. Kiyama, R. and T. Makita, "Improved Viscometer for Compressed Gases and the Viscosity of Oxygen", Rev. Phys. Chem. (Japan) 26, 70 (1956).

8. Luker, J.A. and C.A. Johnson, "Viscosity of Helium, Oxygen, Helium-Oxygen, Helium-Steam, and Oxygen-Steam Mixtures of High Temperatures and Pressures", J. Chem. Eng. Data 4, 176 (1959).

9. Trantz, M. and R. Zink, "Viscosity, Heat Conduction and Diffusion in Gas Mixtures, XII. Viscosity of Gases at High Temperatures, Am. Physik (5) 7, 427 (1930).

Data for the viscosity at atmospheric pressure at temperatures below ambient were taken from Johnston and McCloskey (4), and at higher temperatures from Hilsenrath and Touloukian (3). These data were confirmed by the low pressure data from other sources (1, 2, 5, 6, 7, 8).

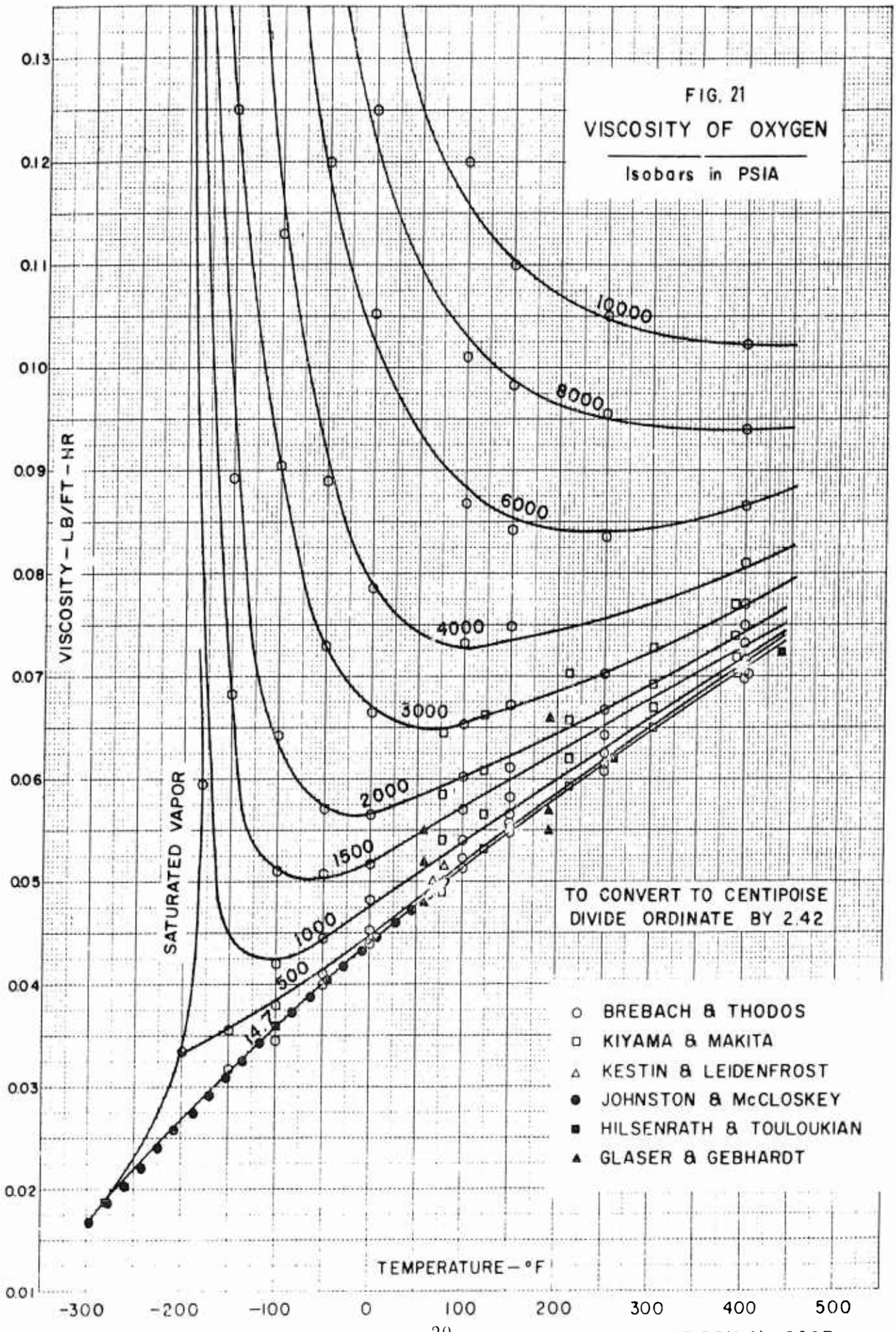
Data for viscosity of compressed oxygen are available at temperatures of ambient and above (2, 5, 6, 7, 8) at pressures up to 2000 psia. No direct data were found for lower temperatures or for higher pressure regions. In these areas the correlation of Brebach and Thodos (1) was used.

The atmospheric data of Johnston and McCloskey (4) along with that of Trantz and Zink (9) and four other investigators were compared by Hilsenrath and Touloukian (3). Agreement within $\pm$ 1% was found in all the data sources at temperatures below 1000°K. Thus a 1% reliability can be expected in these data.

Experimental data on viscosity of oxygen at pressures above atmospheric are shown in Figure 21 (2, 5, 6, 7, 8). The data are extremely limited in scope and are not in good agreement. Only the data by Kestin (5) appear to be reliable and these agree with the correlation of Brebach and Thodos (1).

The oxygen viscosity data are well substantiated at atmospheric pressure where an accuracy of $\pm$ 1% can be expected. The affect of pressure can be obtained only from a correlation based primarily on nitrogen data. Experimental data showing the effect of pressure are scanty and contradictory. Thus the data presented for the viscosity of compressed oxygen are probably accurate to $\pm$ 10% in the pressure range below 3000 psi and at temperatures above 0°F. Outside of this region an accuracy of $\pm$ 20% can be expected.

The tabulated data are given in Table II .



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C. Viscosity of Air

Sources of Data:

1. Brebach, W.J. and G. Thodos, "Viscosity-Reduced Correlation for Diatomic Gases", Ind. Eng. Chem. 50, 1095 (1958).

2. Codegone, C., "Dynamic Viscosity of Gases and Vapors", Atti accord. Sci. Torino Classe Sci. Fis. Mat. e. Nat. 86, 126-8 (1951-2).

3. Glaser, F. and F. Gebhardt, "Viscositatsmessungen an Gasen und Dampfen im Hochdruckgebeit und bei hohen Temperaturen", Chem-Ing-Tech 31, 743 (1959).

4. Golubev, I. F., "The Viscosity of Gases and Gaseous Mixtures at High Pressures I.", J. Tech. Phys. USSR 8, 1932 (1938).

5. Hilsenrath, J. and Y.S. Touloukian, "The Viscosity, Thermal Conductivity and Prandtl Number for Air, Oxygen, Nitrogen, Nitric Oxide, Hydrogen, Carbon Monoxide, Carbon Dioxide, Water, Helium, and Argon, Trans. ASME 76, 967 (1954).

6. Iwasaki, H., "Measurement of Viscosity of Gases at High Pressures. I. Viscosity of Air at 50°, 100°, and 150°C.", Science Reports, Tohoku Univ., Japan 3A, 247 (1951).

7. Johnson, A.I., C. J. Huang, and J.D. Kemp, "Chart for Getting Vapor Viscosities", Chem. Eng. 61, No. 12, 195-6 (1954).

8. Johnston, H.L. and K.E. McCloskey, "Viscosities of Several Common Gases between 90°R and Room Temperature", J. Phys. Chem. 44, 1038 (1940).

9. Kestin, J., and W. Leidenfrost, "Absolute Determination of the Viscosity of Eleven Gases over a Range of Pressures", Physica 25, 1033-62 (1959).

10. Kestin, J., and K. Pilarczyk, "Measurement of the Viscosity of Five Gases at Elevated Pressures by the Oscillating Disk Method", Trans. ASME 76, 987 (1954).

11. Nasini, A. G., and G. Pastonesi, "Viscosity of Air up to 200 Atmospheres", Gazz, Chimica Italiana 63, 821 (1933).

Data at atmospheric pressure and at temperatures below ambient were taken from Johnston and McCloskey (8). For higher temperatures the correlation of Hilsenrath and Touloukian (5), based on the experimental data of 20 investigators was used. This correlation is:

$$\mu \times 10^7 = 145.8\ (T)^{3/2}/(T + 10.4)$$

where μ = viscosity, poise

T = temperature, °K

The high pressure data presented have been calculated from the correlation of Brebach and Thodos (1).

Eleven sources of data on the viscosity of air at atmospheric pressure were analyzed and compared by Hilsenrath and Touloukian (5). These included the data of Johnston and McCloskey (8) in the low temperature range. The data sources agreed within ± 1% at temperatures below 800°K. Thus the data at atmospheric pressure reported here should be reliable within ± 1%.

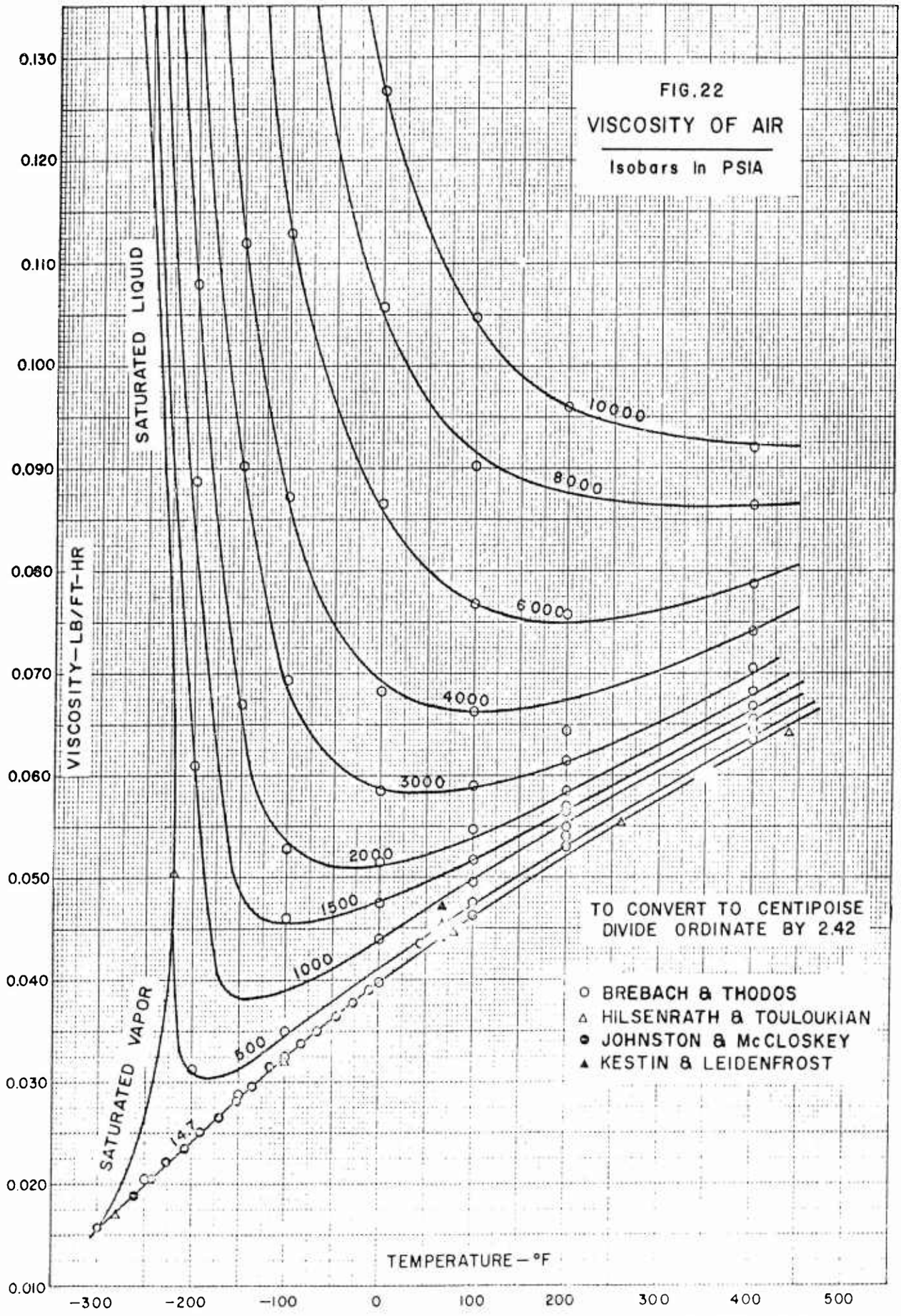
Several investigators have measured the effect of pressure on the viscosity of air (3, 4, 6, 9, 10, 11). However, all of these data were collected at temperatures equal to or greater than ambient and at pressures below 6000 psia. Some of these data are compared with the results reported in Figure 22. The data of Glaser and Gebhardt (3) were obtained with a falling ball viscosimeter and are reported only graphically. The original source gives no estimate of accuracy. The data do not agree with the present results, even at one atmosphere. The data of Kestin and Leidenfrost (9) and of Golubev (4) agree well with the results reported. The greatest discrepancy is about 2% in the viscosity value of Golubev at 2000 psia and 100°C. Hilsenrath shows that the data of Iwasaki (6) and of Nasini and Pastonesi (11) do not agree with that of Golubev. Thus only the results of Kestin (9, 10) and of Golubev (4) are consistent with the calculated values presented here. Despite the limited range of these data, they lend strong support to the calculated values, since the Kestin (9, 10) data have been obtained so carefully.

The correlation of Brebach and Thodos (1) is the major source of the data presented. This correlation is based on the corresponding states principle and the extensive available data on nitrogen. Since air is largely nitrogen, this approach should be applicable, and has been frequently used in the past. In this case, the residual viscosity of nitrogen was found to be a function of the density of nitrogen. A similar relation was found for other gases. This relation was used to extend the nitrogen data into regions where data were lacking. Although the correlation predicts the available data by about $\pm$ 3%, it is probably reliable only to within $\pm$ 10% in the area near the critical temperature. The correlation gives the viscosity in the reduced form, μ / μ_c. The critical viscosity, μ_c, was taken as 0.048 lb/ft-hr, a compromise between the value of 0.0496 given by Johnson, et al (7), and that of 0.0473 given by Codegone (2).

Figure 22, showing the viscosity of gaseous air, is based on experimental data for viscosity at atmospheric pressure, and on a corresponding-states correlation for high pressure data. The high pressure data are corroborated with experimental data only in the ambient temperature range.

The data at atmospheric pressure are probably reliable to $\pm$ 1%. The high pressure data are probably reliable to $\pm$ 5% at temperatures above 0°F, and pressures below 2000 psia, and to $\pm$ 10% at temperatures below 0°F and at pressures above 2000 psia.

The tabulated data are given in Table III.



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D. Viscosity of Saturated Liquids

Sources of Data:

1. Brebach, W. J. and G. Thodos, "Viscosity-Reduced State Correlation for Diatomic Gases", Ind. Eng. Chem. 50, 1095-100 (1958).

2. Hirschfelder, J.O., C. F. Curtiss, and R.B. Bird, Molecular Theory of Gases and Liquids, John Wiley and Sons, Inc., New York (1954), p. 630.

3. Johnson, V.J., A Compendium of the Properties of Materials at Low Temperatures, (Phase I) WADD-TR-60-56, Oct. 1960, p. 10.004.

4. Rudenko, N.S., "Viscosity of Liquid Oxygen, Nitrogen, Methane, Ethylene, and Air", J. Exptl. Theoret. Phys (USSR) 9, 1078 (1939).

5. Rudenko, N.S. and L. V. Shubnikow, "Viscosity of Liquid Nitrogen, Carbon Monoxide, Argon and Oxygen and its Dependence on Temperature", Physik.Z. Sowjetunion 6, 470-7 (1934).

6. Van Itterbeek, A. and O. van Paemel, "Determination of the Viscosity of Liquid Hydrogen and Deuterium", Physica 8, 133 (1941).

Oxygen

The data of Rudenko and Shubnikow (5) were plotted over the range -361.8° to -315.7°F. Values from Van Itterbeek and Van Paemel (4) were plotted over the range -336.1 to -297.3°F and showed close agreement with the data of Rudenko and Shubnikow in the common temperature range. The spread of points about the smoothed curve over the range, -361.8 to -315.7°F, is $\pm$ 2-3% in most cases, as shown in Figure 23.

At higher temperatures, the data of Rudenko (4) over the range, -259.9 to -182.3°F, indicate that the viscosity-temperature curve should be hyperbolic (concave-upward), even at temperatures very close to the critical temperature (-181.1°F). However, from considerations of continuity of the saturation curve, and the

shape of the saturated vapor viscosity curve, it was believed that the values of Rudenko (4) were unreliable over the range, -233.3 to -182.3°F, and, instead, values from the reduced viscosity correlation of Brebach and Thodos (1) were used to define the curve near the critical point. The range over which these values were used was -225.7 to 181.1°F. It is significant to note that although Brebach and Thodos (1) claim large deviation from experimental values when the reduced correlation is used for liquid oxygen, the experimental values, in this case, were probably those of Rudenko (4), which seem very doubtful. In view of this, it does not seem possible to estimate the uncertainty introduced by using the correlation of (1).

The tabulated data are given in Table IV.

Nitrogen

Two sets of data were plotted from Brebach and Thodos (1). Data were taken from a plot of μ_r vs. T_r which utilized literature values in drawing a saturated liquid curve. The range used was approximately -335°F to -255°F. Another set of data was taken from a plot of residual viscosity, $\mu - \mu$ vs. the density, in which the temperature range used was -340°F to -235°F. Some uncertainty exists in the values taken from these plots since the graphs were small and contained no auxiliary grid lines. Moreover, one of the plots has a very large slope in the region from which some values were taken. The estimated uncertainty in the reading of these graphs is approximately 5 10%. Hence, values from these were not assigned primary weight in plotting the viscosity curve, where experimental data were available.

Primary weight was given to the data of (3) and (6) in drawing the curve from -346°F to -280°F. At higher temperatures, the available data from (3) indicates that the μ - T curve is hyperbolic, while considerations of continuity at the critical point lead to the conclusion that the curve must have an infinite slope at the critical temperature and that an inflection point exists. This inflection point was drawn at about -270°F, and, using some values from (1) as a guide, the curve was extended to the critical viscosity as shown in Figure 23. In doing so, the values from (3) and from Brebach and Thodos (1) were not given primary weight.

Agreement of values from all sources in the range, -346 to -280°F, is good. The spread of points about the curve in this range averages about $\pm$ 2%. The points from (3) were given primary weight over this range. At temperatures above -280°F, uncertainties in the values as high as $\pm$ 10% are possible.

The tabulated data are given in Table V.

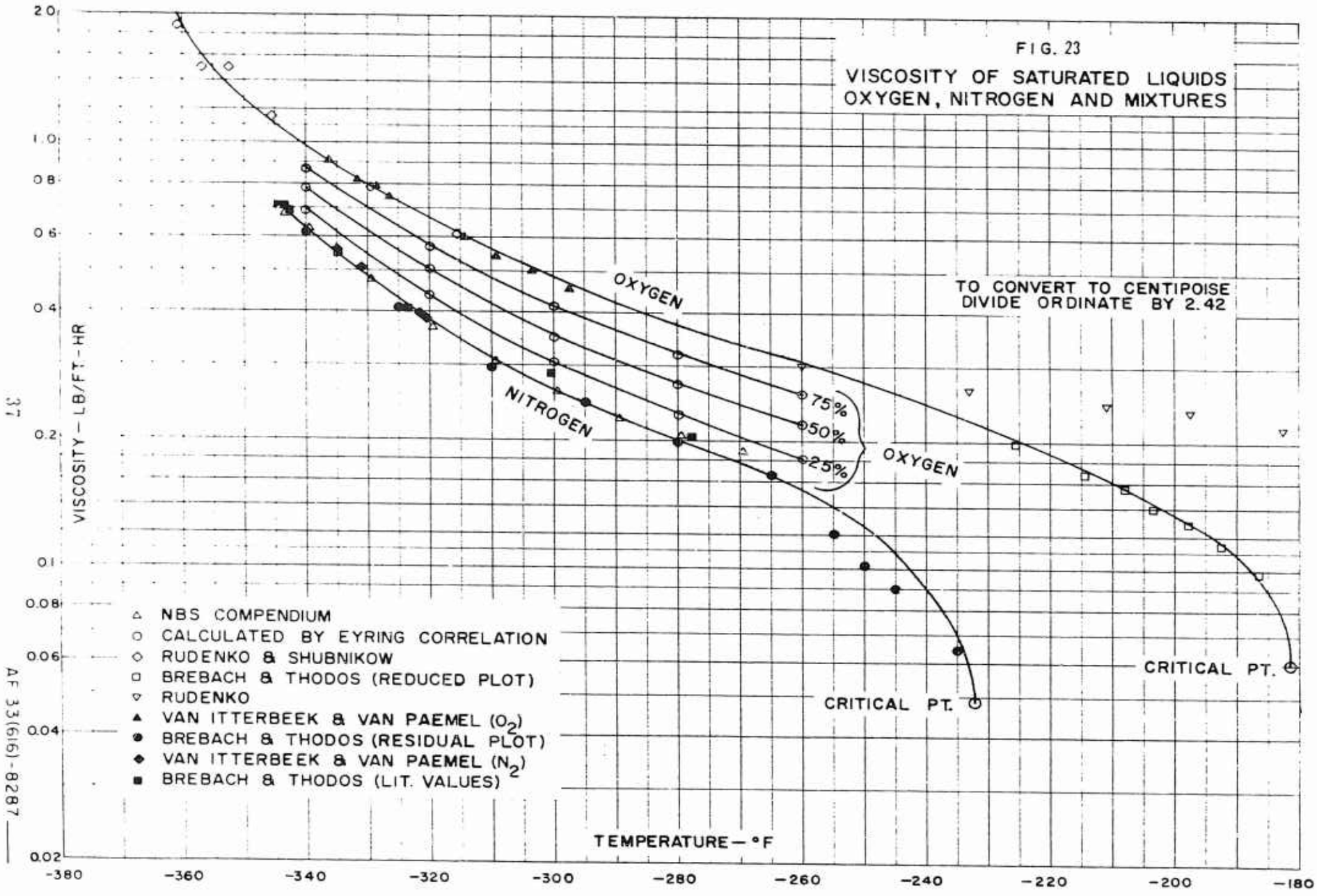
Nitrogen-Oxygen Mixtures

The correlation for the viscosities of liquid mixtures suggested by Hirschfelder, et al (1) was used to construct curves for 25, 50, and 75% O_2 in N_2-O_2 mixtures of Figure 23. The correlating equation due to Eyring was as follows:

$$\log \mu_{mix} = X_1 \log \mu_1 + X_2 \log \mu_2$$

Here X_1 and X_2 are mole fractions, μ_1 and μ_2 are viscosities of the pure components, and μ_{mix} is the viscosity of the mixture, all at the same temperature. The temperature range covered was from -340 to -260°F. In this temperature range, the most reliable viscosity data for pure oxygen and pure nitrogen were obtained. Auxiliary viscosity graphs gave a virtual straight line when log μ was plotted against the reciprocal temperature over this range. At higher temperatures, near the critical, the uncertainity of the pure component viscosities increased considerably.

The tabulated data are given in Table VI.



AF 33(616)-8287

E. Dew Points, Bubble Points, and Vapor-Liquid Equilibrium Ratios

Sources of Data:

1. Armstrong, G.T., J.M. Goldstein, and D.E. Roberts, "Liquid-vapor Phase Equilibrium in Solutions of Oxygen and Nitrogen at Pressures below One Atmosphere", J. Res. Nat. Bur. Stds. 55, 265-77 (1955).

2. Baly, R., "On the Distillation of Air, and the Composition of Gaseous and Liquid Phases", Phil. Mag. (V) 49, 517 (1900).

3. Cockett, A.H., "The Binary System Nitrogen-Oxygen at 1.3158 Atmospheres", Proc. Roy. Soc. (London) A 239, 76-92 (1947).

4. Din, F., "Liquid- vapour Equilibrium of the System Nitrogen and Oxygen at Pressures up to 10 Atm.", Trans. Faraday Soc. 56, 668-81 (1960).

5. Din, F., "Thermodynamic Functions of Gases, Vol. 2", Butterworth Scientific Pub., London (1956), p. 46-9.

6. Dodge, B.F., "Isotherms and Isobars for Air Separation Studies", Chem. Met. Eng. 35, No. 10, 622 (1928).

7. Dodge, B.F., and H.W. Davis, "Vapor Pressure of Liquid Oxygen and Nitrogen", J. Am. Chem. Soc. 49, 610 (1927).

8. Dodge, B.F. and A.K. Dunbar, "Investigation of the Co-existing Liquid and Vapor Phases of Solutions of Oxygen and Nitrogen", J. Am. Chem. Soc. 49, 591 (1927).

9. Friedman, A.S. and D. White, "The Vapor Pressure of Liquid Nitrogen", J. Am. Chem. Soc. 72, 3931-32 (1950).

10. Hausen, H., "Rectification of Ternary Mixtures. Especially Oxygen-Nitrogen-Argon Mixtures", Forsch. Ingenieurw. 6A, 9-22 (1935).

11. Henning, F., "The Gas and Resistance Thermometer in the Temperature Region of Liquid Nitrogen and Hydrogen", Z. Physik 40, 775-85 (1927).

12. Hoge, H.J.,"Vapor Pressure and Fixed Points of Oxygen and Heat Capacity in the Critical Region", J. Res. Nat. Bur. Stds. 44, 321 (1950).

13. Komorov, P., A. Likhter, and M. Rueman, "The Diagrams of State of Mixtures Fusing at Low Temperatures System Nitrogen-Oxygen and Nitrogen-Carbon Monoxide", J. Tech. Phys. (USSR) 5, 1723-8 (1935).

14. Krichevskii, I. R., and N.S. Tarochesnikov, "Thermodynamics of the Liquid-Gas Equilibrium in the Nitrogen-Oxygen System", Z. Physik. Chem. A 176, 338-46 (1936).

15. Kuenen, J.P. and A.L. Clark, "Critical Point Phenomena and a Few Condensation Constants of Air", Commun. Phys. Lab. Univ. Leiden No. 150 b (1917).

16. Kuenen, J.P., T. Verschoyle, and A.D. van Urk, "Isotherms of Diatomic Substances and Their Binary Mixtures, Critical Phenomena and Some Isotherms of The Mixtures, with 50% and 75% by Volume of Oxygen In the Neighborhood of the Critical Point", Proc. Acad. Sci. Amsterdam 26, 49-64 (1923).

17. Latimer, R.E. "Vapor-liquid Equilibrium of Nitrogen-Argon-Oxygen Mixtures", A.I. Ch.E. Journal 3, 75 (1957).

18. Michels, A., T. Wassenaar, W. de Graaf and C. Prins, "Vapor Pressure of Liquid Nitrogen, Physica 19, 26-8 (1953).

19. Weishaupt, J., "Determination of the Phase Equilibria of Nitrogen-Argon-Oxygen Mixtures at a Pressure of 1000 Tarc. (1000 mm Hg)", Angew. Chem. B 20, 321 (1948).

The 100% oxygen data on the dew and bubble point curves is the vapor pressure of oxygen. This was taken directly from the data of Hoge (12). Similarly the 0% oxygen curves are identical to the vapor pressure of nitrogen. These data were obtained from Michels et al (18), Friedman and White (9), Dodge and Davis (7), and Henning (11).

These vapor pressure relations also determine the points of intersection of

These vapor pressure relations also determine the points of intersection of the K-value curves with the K=1 line, and the ends of these lines in the sub-critical region. The critical point for 21% oxygen was taken as that for air reported by Kuenen and Clark (15), while the rest of the critical envelope is that of Kuenen, Verschoyle, and van Urk (16). The K-value charts are not extended into the critical region.

Data in the two-component region on the dew and bubble point charts and on the K-value plots were obtained from Dodge and Dunbar (8). These investigators report isotherms and isopiestics for the oxygen-nitrogen system over the entire composition range. Pressures ranged from 0.75 to .32 atm. and temperatures from 72 to 133°K. These results were correlated by three equations which allow interpolation. These interpolation formulas were used in constructing the charts discussed here.

In obtaining the dew point plots the original data of Dodge and Dunbar (8) were plotted as isotherms on P-x and P-y coordinates Values from the P-y coordinates are not included here.

In obtaining the K-value charts the interpolation equations of Dodge and Dunbar were used to obtain tabular K data as functions of X_{O_2} and T, and also to obtain tabular P data as functions of X_{O_2} and T. These tables were used simultaneously to obtain K as functions of P and T.

The vapor pressure data for oxygen (12) and for nitrogen (7, 9, 11, 18) appear highly reliable. The various sources for nitrogen agreed with each other within a maximum deviation in pressure of $\pm$ 1%. The data of Hoge (12) for oxygen, when compared with earlier investigators (5, 10) show maximum deviations of 0.5%. Thus a reliability within $\pm$ 1% can be expected for the 0% and 100% oxygen data.

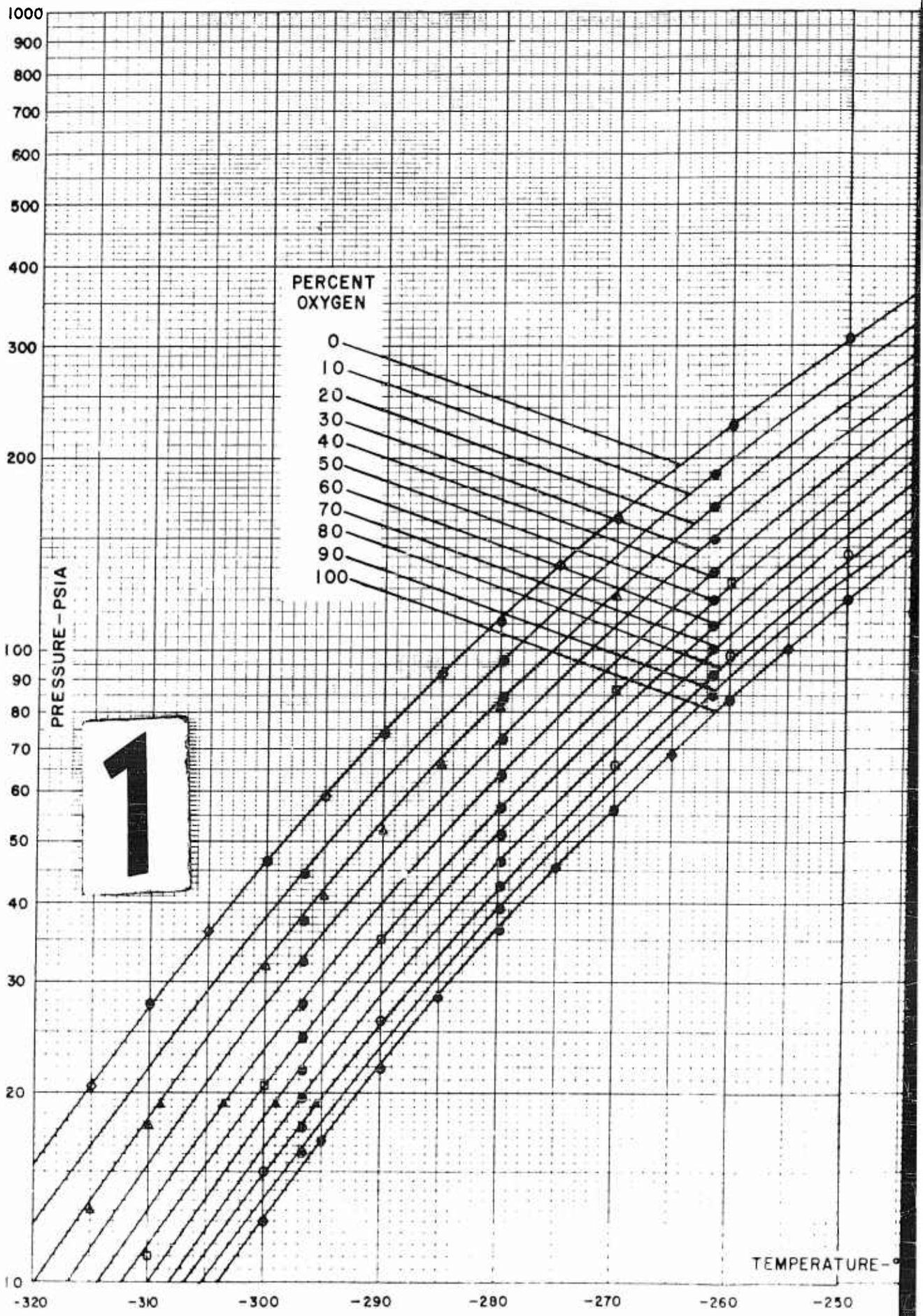
The critical locus is somewhat less precisely determined. Though the data of Kuenen and Clark (15) and of Kuenen, Verschoyle and van Urk (16) are internally smooth and in substantial agreement, the nature of measurements in the critical region makes it almost impossible to determine precise phase boundaries. Thus a precision of $\pm$ 1°F must be expected in this region.

The data of Dodge and Dunbar (8) for the two-component region were obtained in a vapor-recycle equilibrium cell. Temperature control was obtained by control of pressure over boiling liquid oxygen. Temperatures were measured with calibrated thermocouples to an accuracy of about $\pm$ 0.1°C. Pressures were measured

by manometers and a dead-weight pressure gage. Comparative measurements agreed within an average deviation of 0.008%. Sampling and analysis by absorption in potassium pyrogallate solution give check samples agreeing with 0.2%. These data have been examined closely by many investigators over the years, two recent cases being those of Latimer (17) and Din (5) and Cockett (3). In all cases the Dodge and Dunbar data have been found to be the best available. Din reports that the temperature scale used by Dodge and Dunbar was in error by 0.5°C at the methane point, reflecting similar errors in the final data at the higher temperatures. He also reports that analysis of the data shows that they lack thermodynamic consistency at high temperatures and pressures. Thus these data are probably accurate to 0.1°C at pressures close to atmospheric but to about 1°C at pressures above 100 psia. Above -240°F the data have been extrapolated. Although a reduced accuracy would thus be expected, the limits imposed by the 0 and 100% oxygen curves and the critical locus probably ensure a continuation of the accuracy limit of 1°C.

Summarizing graphs showing the dew points, bubble points, and oxygen and nitrogen K-values have been prepared and presented in Figure 24 and 27 inclusive. In the single-component limits these are based on extensive experimental values of many investigators (1, 4, 7, 9, 12, 16, 18) accuracy should be better than 0.1°F. In the two-component region the data of Dodge and Dunbar (8) were the major sources but the data of Din (4) and Cockett (3) were also used. These data are accurate to 0.1°F in temperature or 2% in K-value at pressure below 100 psia. At higher pressures accuracy is expected to be less, in the order of 1°F in temperature or 5% K-value.

The tabulated data are given in Table VII.


1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
PRESSURE – PSIA
PERCENT OXYGEN
0
10
20
30
40
50
60
70
80
90
100
1
-320
-310
-300
-290
-280
-270
-260
-250
TEMPERATURE-°

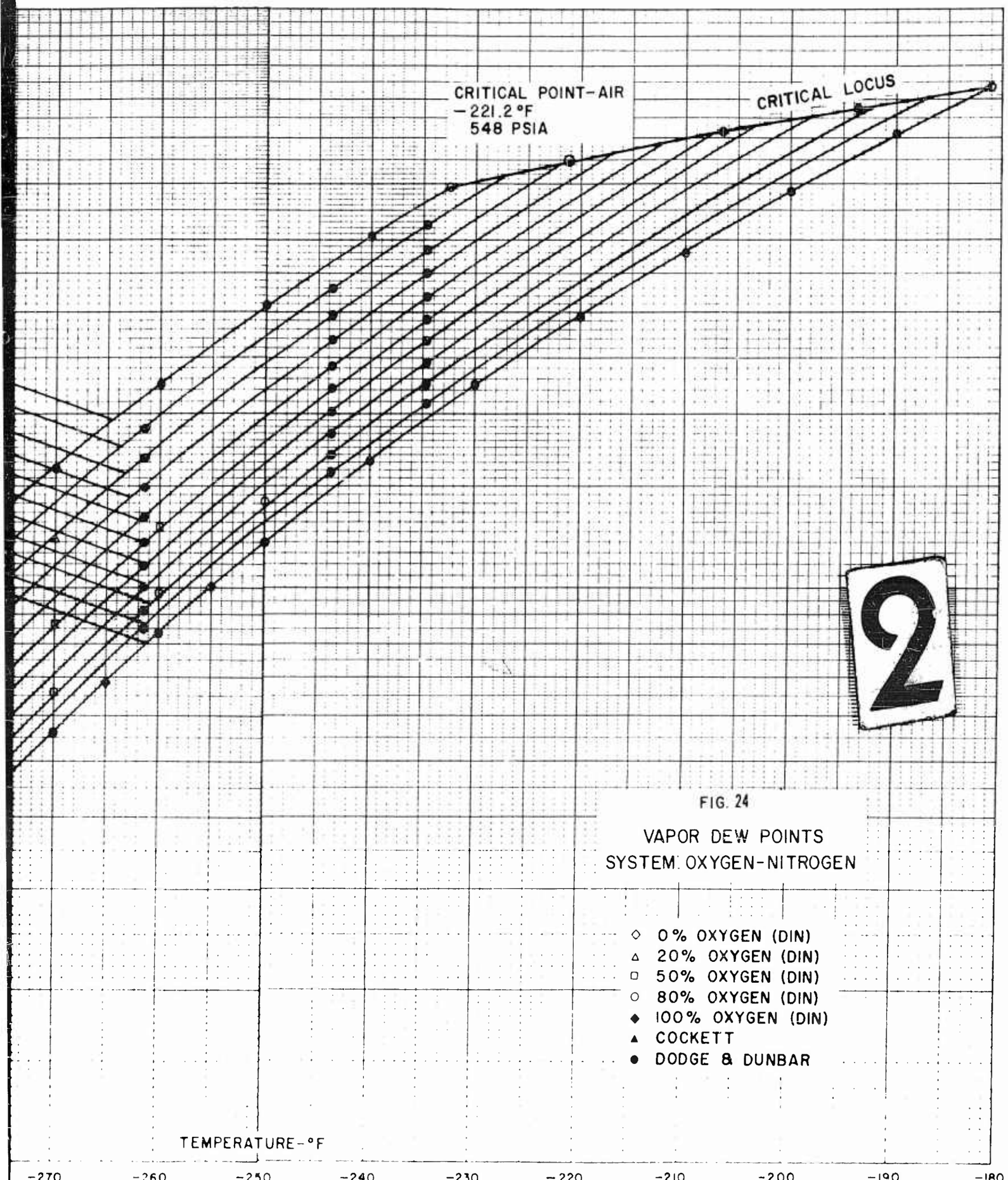
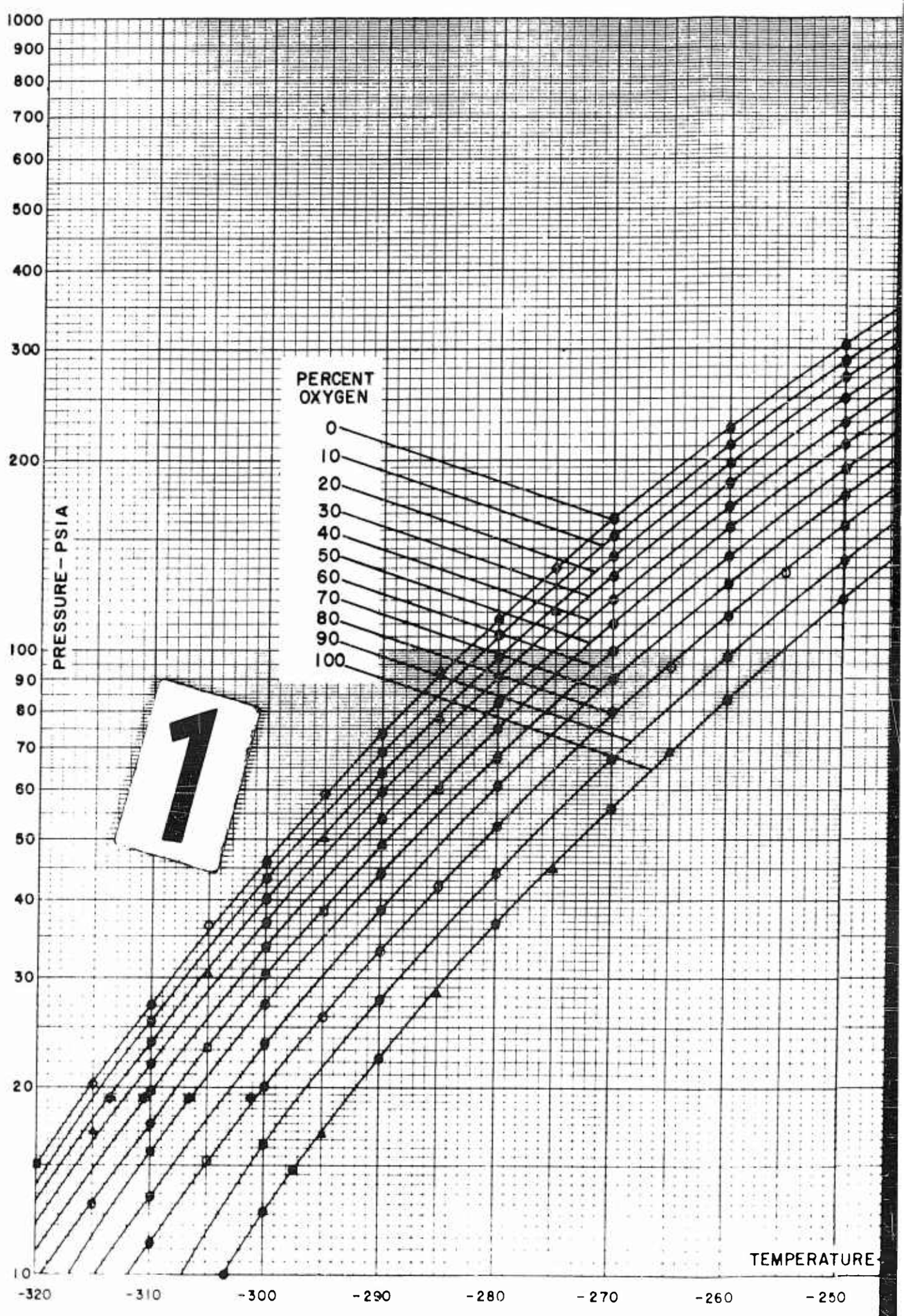


FIG. 24

VAPOR DEW POINTS
SYSTEM: OXYGEN-NITROGEN


PRESSURE - PSIA
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
PERCENT OXYGEN
0
10
20
30
40
50
60
70
80
90
100
1
TEMPERATURE
-320
-310
-300
-290
-280
-270
-260
-250

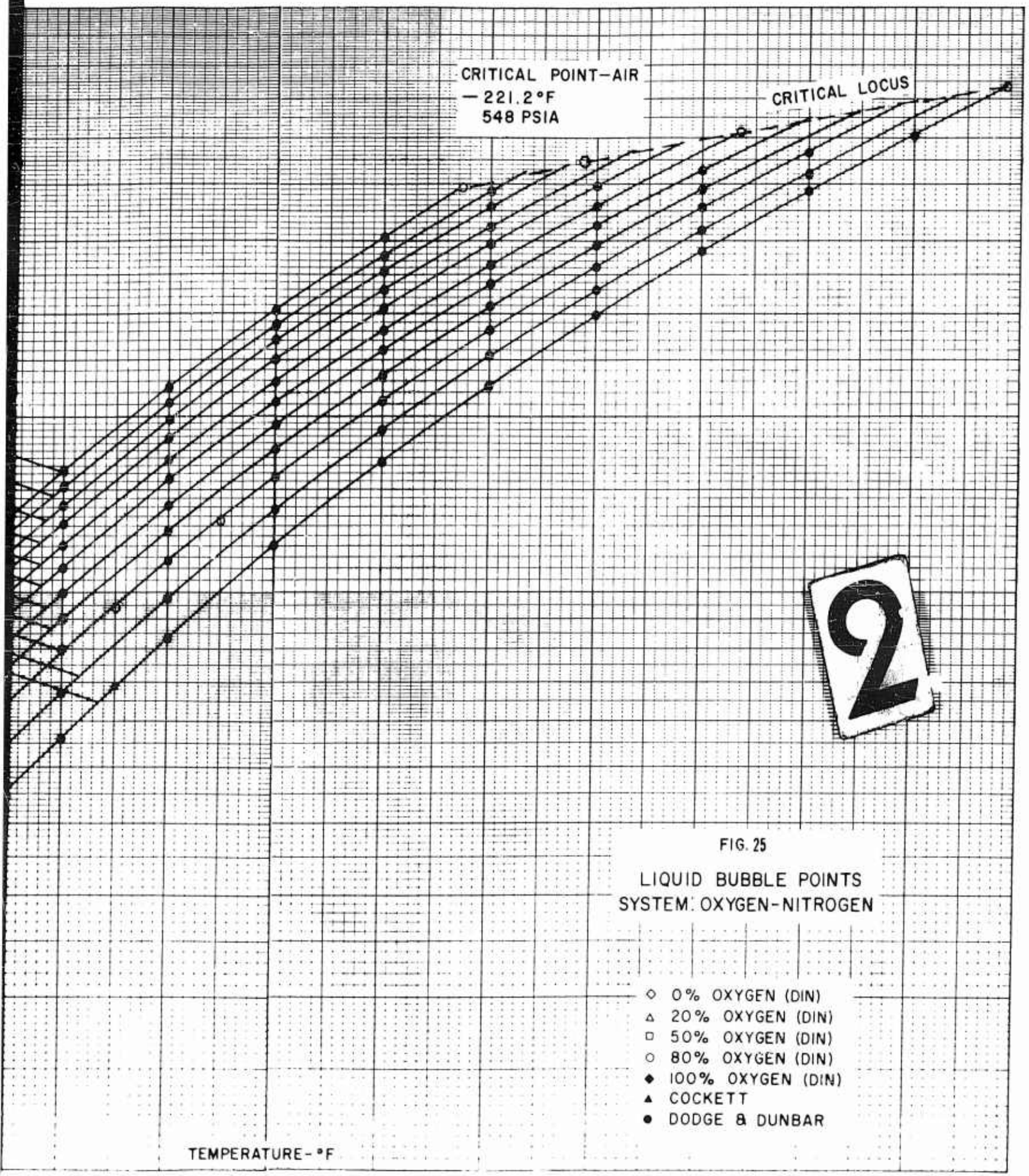


FIG. 25

LIQUID BUBBLE POINTS
SYSTEM: OXYGEN-NITROGEN

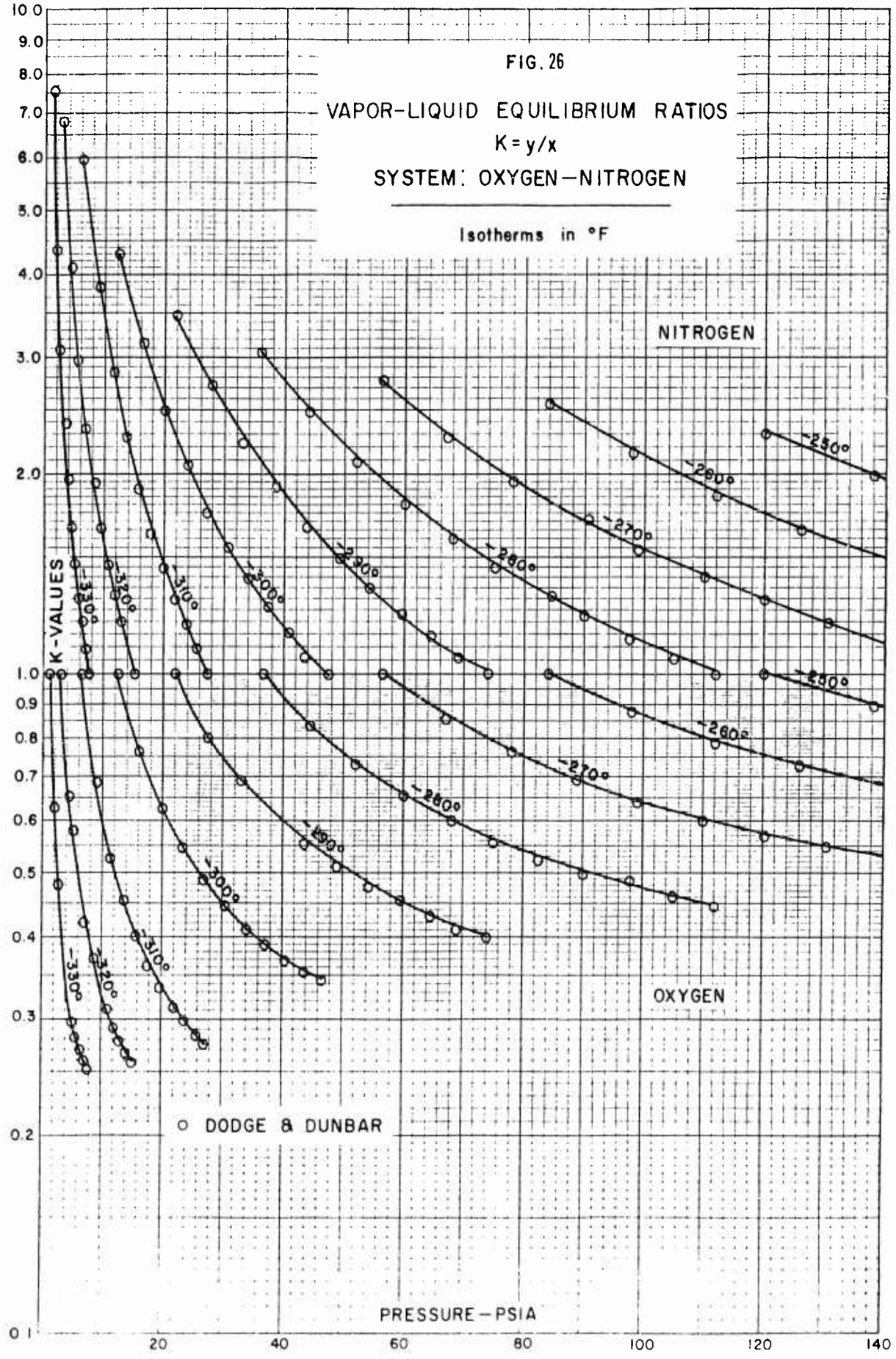


FIG. 26
VAPOR-LIQUID EQUILIBRIUM RATIOS
K = y/x
SYSTEM: OXYGEN—NITROGEN
Isotherms in °F
NITROGEN
OXYGEN
K-VALUES
PRESSURE—PSIA
DODGE & DUNBAR
-250°
-260°
-270°
-280°
-290°
-300°
-310°
-320°
-330°
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
20
40
60
80
100
120
140

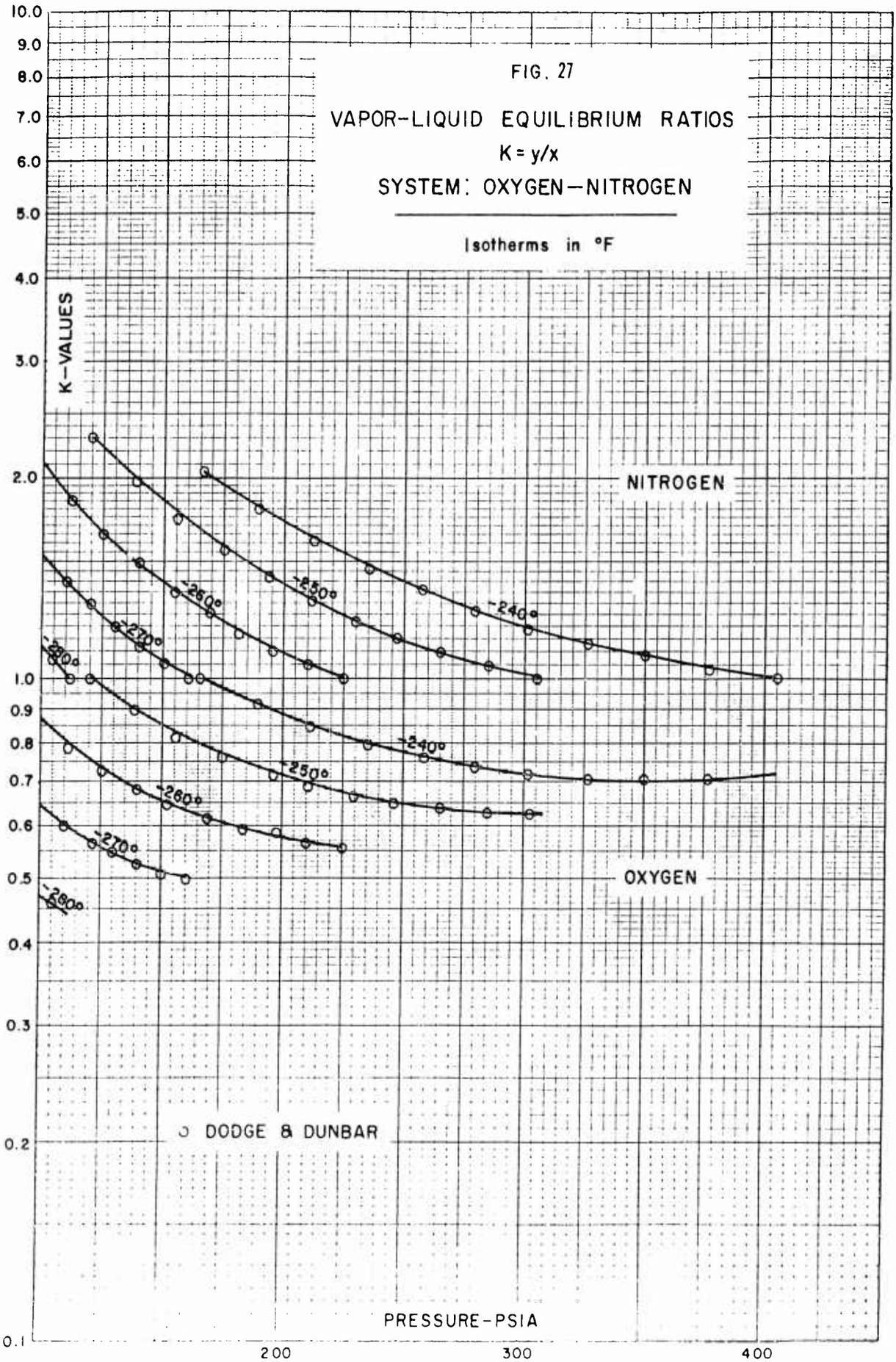


FIG. 27
VAPOR-LIQUID EQUILIBRIUM RATIOS
K = y/x
SYSTEM: OXYGEN—NITROGEN
Isotherms in °F
K-VALUES
NITROGEN
OXYGEN
-230°
-240°
-260°
-270°
-280°
-240°
-250°
-260°
-270°
-280°
○ DODGE & DUNBAR
PRESSURE-PSIA
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
200
300
400

F. Thermal Conductivity of Nitrogen

Sources of Data:

1. Hilsenrath, J., et al., "Tables of Thermal Properties of Gases", NBS Cir. 564 (1955).

2. Johnson, V.J., "A Compendium of the Properties of Materials at Low Temperatures", (Phase I) WADD-TR-60-56, Oct., 1960, p. 3.004.

3. Lenoir, J.M., W.A. Junk, and E.W. Comings, "Measurement and Correlation of Thermal Conductivities of Gases at High Pressures", Chem. Eng. Prog. 49, 539-42 (1953).

4. Michels, A., "Viscosity and Heat Conductivity of Gases (and Liquids) in the Neighborhood of Condensation Region", Proc. Intern. Symp. on Transp. Process in Stat. Mech., Brussels, 1956, 365-375 (Pub. 1958).

5. Nuttall, R.L. and D.C. Ginnings, "Thermal Conductivity of Nitrogen from 50° to 500°C and 1 to 100 Atm.", J. Res. NBS 58, 276 (1957) (Research Paper 2760).

6. Owens, E.J. and G. Thodos, "Thermal Conductivity-Reduced State Correlation for the Inert Gases", A.I.Ch.E. Journal 3, 459-60 (1957).

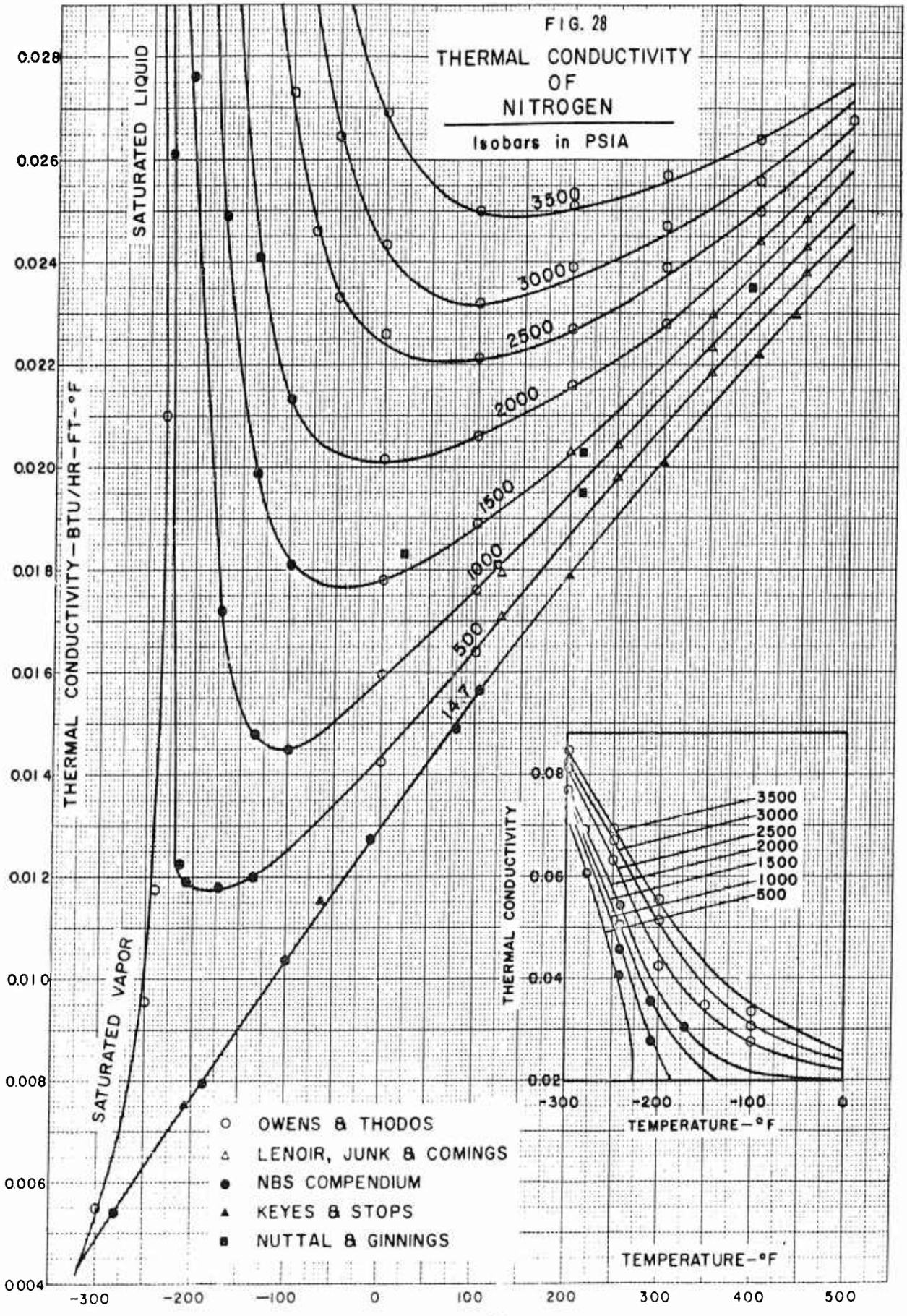
The data have been presented graphically in Figure 28 covering thermal conductivity values of 0.004 to 0.029 Btu/Hr-Ft-°F, and in inset furnishing values to approximately 0.085 Btu/Hr-Ft-°F. The inset was used because some experimental data at values above 0.29 Btu/Hr-Ft-°F were available; it was also desired to show the lower range as accurately as possible.

The reduction envelope was constructed using the correlation of Owens and Thodos (6) and from which the critical thermal conductivity was taken to be 0.02099 Btu/Hr-Ft-°F. The saturated liquid curve was not included in the inset. At 14.7 psia, experimental data from the NBS Compendium (2) and values from the NBS Circular 564 (1), based on the work of Keyes and Stops, were available. The values from the NBS Circular 564 (1) were not given primary weight in plotting this

isobar, except at higher temperatures, where they were the only experimental data available. The values from the NBS Circular 564 (1) were not given primary weight in plotting this isobar, except at higher temperatures, where they were the only experimental data available. Some experimental values were available up through 2000 psia. The data from the NBS Compendium (2) were used at low temperatures, and scattered experimental values from Lenoir, et al (3) and Nutall and Ginnings (5) were also included in plotting the isobars. Data points in the high temperature regions were obtained using the correlations of Lenoir, et al (3) and Owens and Thodos (6). The isobars higher than 2000 psia were plotted using only the correlation from Owens and Thodos (6).

In all cases, experimental data were more heavily weighted than correlative values in plotting the curves. The data from Hilsenrath, et al (1) are claimed to be reliable to within about 2%. Nutall and Ginnings (5) claim an uncertainty of only 0.5 - 1.5%, but their results differ substantially from those of the other investigators. Lenoir, et al (3) admit that their molecular model may be oversimplified; this would decrease the reliability of their correlation. Owens and Thodos (6), comparing correlation values to experimental values, find an average deviation for the correlation of 2.6%, with a maximum deviation of 8.4%. In view of the above discussion, it is probable that for the curves or parts of curves determined from experimental data, the uncertainty is no greater than 2 to 3%. For the regions where correlations were used, an average uncertainty of $\pm$ 3 to 4% with maximums approaching $\pm$ 9 to 10% may be expected.

The tabulated data are given in Table VIII.



AF 33(616)-8287

G. Thermal Conductivity of Oxygen

Sources of Data:

1. Hilsenrath, J. et al, "Tables of Thermal Properties of Gases", NBS Cir. 564, 425 (1955).

2. Johnson, V.J., "A Compendium of the Properties of Materials at Low Temperatures" (Phase I) WADD-TR-60-56, Oct., 1960, p. 3.005.

3. Lenoir, J.M., W.A. Junk, and E.W. Comings, "Measurements and Correlation of Thermal Conductivities of Gases at High Pressures", Chem. Eng. Prog. 49, 539 (1953).

4. Owens, E.J. and G. Thodos, "Thermal Conductivity-Reduced State Correlation for the Inert Gases", A.I.Ch.E. Journal 3, 459-60 (1957).

5. Tsederberg, N.V. and D.L. Timrot, "Experimental Determination of the Thermal Conductivity of Liquid Oxygen", Zhur. Tekh. Fiz. 26, 1849 (1956).

6. Ziebland, H. and J.T.A. Burton, "The Thermal Conductivity of Liquid and Gaseous Oxygen", Brit. J. Appl. Phys. 6, 416, (1955).

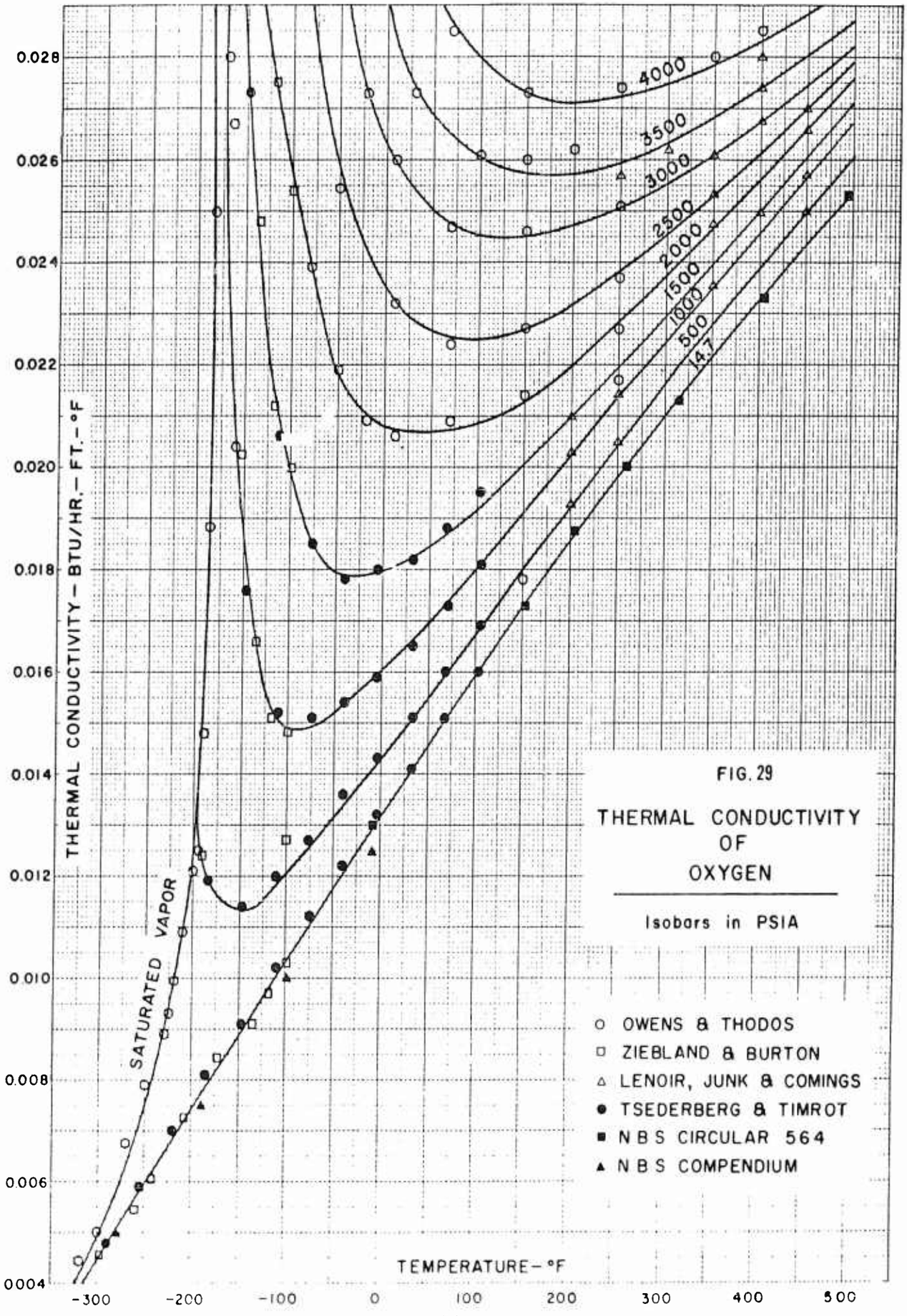
The greatest amount of experimental data for thermal conductivity of oxygen was found for a pressure of 1 atm. At temperatures below 0°F, the 14.7 psia isobar was obtained from the data of the NBS Compendium (2), Tsederberg and Timrot (5), and Ziebland and Burton (6). At higher temperatures, the data plotted were those of Tsederberg and Timrot (5). At the lower temperatures, the deviation of points from the plotted curve as shown in Figure 29 averages about ± 2%, with a maximum of approximately 5%. The data of Tsederberg and Timrot (5) and Ziebland and Burton (6) were weighed about equally, since both sets of data were experimental. At higher temperatures, there was virtually no deviation of the points on the 14.7 psia isobar. The saturated vapor curve was plotted entirely from the correlation of Owens and Thodos (4), according to whom, the average deviation from experimental values is 2.7% for gaseous oxygen.

Experimental data were available from Tsederberg and Timrot (5) and Ziebland and Burton (6) in the regions containing the minima in the isobars through 1500 psia. Experimental agreement is particularly good for the 1000 psia isobar in that region, the deviation of data points being about ± 1%. The correlation of Owens and Thodos (4) and values obtained from Lenoir, et al (3) were used to determine the isobars at the higher temperatures, where no experimental data were available.

The isobars from 2000 psia to 4000 psia, inclusive, were constructed almost entirely from Owens and Thodos (4) and Lenoir, et al (3). The deviation of the data points was ± 1% or less for the 2000, 2500, and 3000 psia isobars, and reached a maximum of 2% for the 3500 psia isobar.

In summary, the error in the thermal conductivity of oxygen in those portions which were determined mainly by experiment is probably ± 2%. while the error in those portions which were determined from correlations is about ± 4 - 5 %

The tabulated data are given in Table IX.



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H. Thermal Conductivity of Saturated Liquid Nitrogen

1. Borovik, E., A. Matveev and E. Panina, "Thermal Conductivity of Liquid Nitrogen, Carbon Monoxide, Methane, and Ethylene", J. of Tech. Physics (USSR) 10, 994 (1940).

2. Owens, E. J. and G. Thodos, "Thermal Conductivity-Reduced State Correlation for the Inert Gases", A.I.Ch.E. Journal 3, 459-460 (1957).

3. Powers, R.W., R.W. Mattox, and H.L. Johnston, "Thermal Conductivities of Condensed Gases. I. The Thermal Conductivity of Liquid Nitrogen between 65° and 90°K", J. Am. Chem. Soc. 76, 5968-73 (1954).

4. Riedel, L., "A New Universal Vapor-Pressure Equation. I. The Extension of the Theorem of Corresponding States", Chem. Ing. Tech. 26, 83 (1954).

5. Riedel, L., "A New Universal Vapor-Pressure Equation. II. Liquid Density in the Saturated State", Chem. Ing. Tech. 26, 259 (1954).

6. Riedel, L., "A New Universal Vapor-Pressure Equation. III. Critical Coefficient, Density of Saturated Vapor, and Latent Heat of Vaporization", Chem. Ing. Tech. 26,679 (1955).

7. Riedel, L., "A New Universal Vapor-Pressure Equation. IV. Compressibility, Surface Tension, and Thermal Conductivity in the Liquid Phase", Chem. Ing. Tech 27, 209 (1955).

8. Uhlir, A., Jr., "Thermal Conductivity of Fluid Argon and Nitrogen", J. Chem. Phys. 20, 472 (1952).

Of the various sets of experimental data used in presenting the thermal conductivity of saturated liquid nitrogen as shown in Figure 30, the data of Powers, et al (3), were weighed most heavily over the temperature range from -336.1 to -301.1°F. At higher temperatures, the correleation of Owens and Thodos (2) received more consideration in plotting. The data of Borovik, et al (1) showed excessive positive deviations from the rest of the data at lower temperatures, from -328 to -301°F, but agreed well with Owens and Thodos (2) over the higher temperature ranges. The correlation of Riedel (4, 5, 6, 7) as well as most of the values

from Uhlir (8) showed large negative deviations from the plotted curve. Values of thermal conductivity for the lower temperatures as taken from references (1, 4, 5, 6, 7, 8) resulted in large deviations from the curve. In plotting, however, they were almost completely ignored, and the resulting agreement between the value of references (3) and (2) is good, being on the order of $\pm$ 2-3% which is approximately average uncertainty of the correlation of Reference (2). The correlation of Riedel (4, 5, 6, 7) on the other hand, has a maximum uncertainty of about 10%, and these values were therefore given little weight.

The tabulated data are given in Table X .

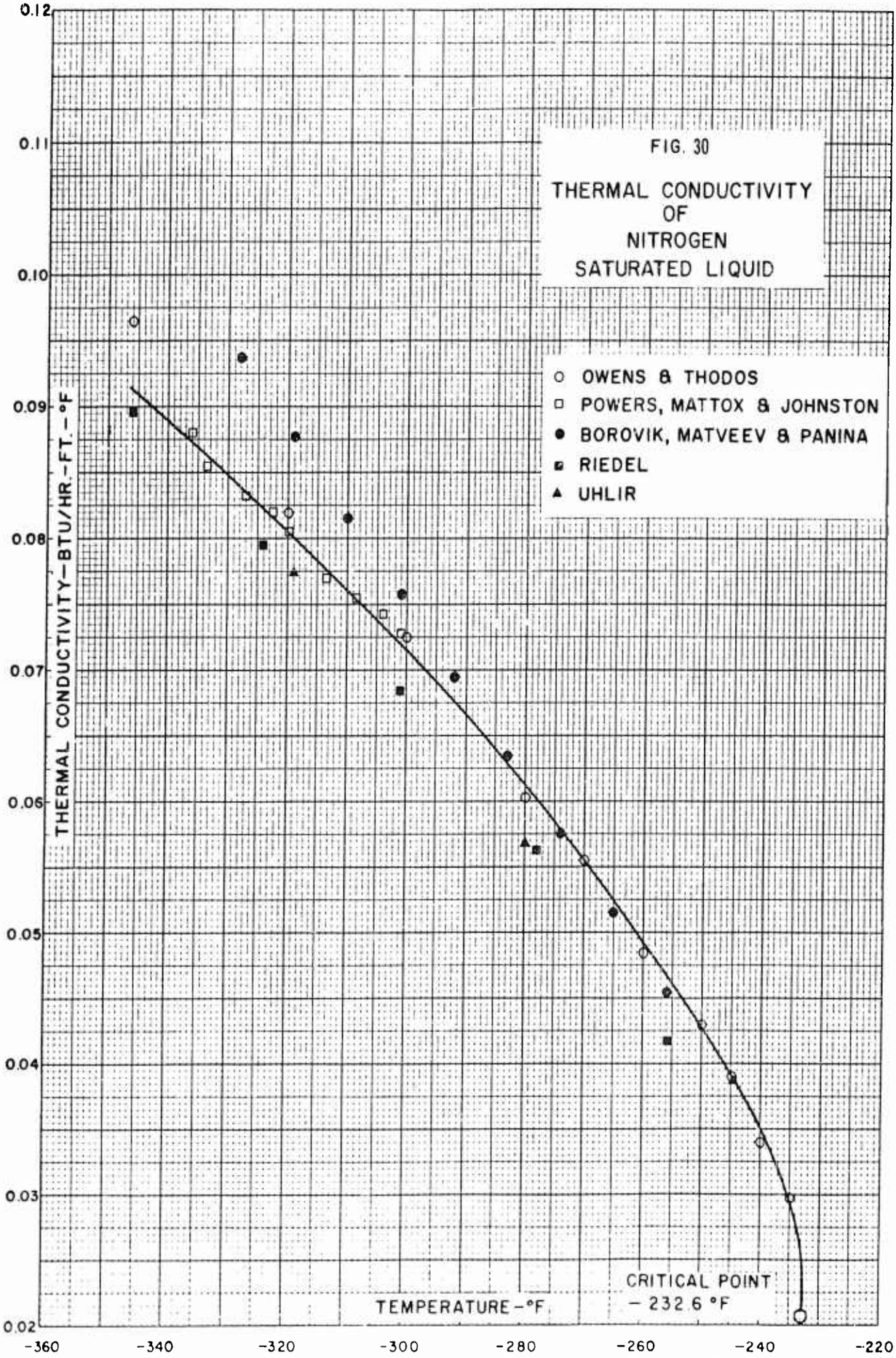


FIG. 30
THERMAL CONDUCTIVITY OF NITROGEN SATURATED LIQUID
OWENS & THODOS
POWERS, MATTOX & JOHNSTON
BOROVIK, MATVEEV & PANINA
RIEDEL
UHLIR
THERMAL CONDUCTIVITY—BTU/HR.-FT.-°F
TEMPERATURE—°F.
CRITICAL POINT
— 232.6 °F
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
-360
-340
-320
-300
-280
-260
-240
-220

I. Thermal Conductivity of Saturated Liquid Oxygen

Sources of Data:

1. Hilsenrath, J., et al, "Tables of Thermal Properties of Gases", NBS Circ. 564, (1955) p. 425.

2. Johnson, V.J., "A Compendium of the Properties of Materials at Low Temperatures" (Phase I) WADD-TR-60-56, Oct., 1960, p. 3.005.

3. Owens, E.J. and G. Thodos, "Thermal Conductivity-Reduced State Correlation for the Inert Gases", A.I.Ch.E. Journal 3, 459-60 (1957).

4. Scott, R. B., "The Density of Liquid Oxygen", NBS Rep. 6752, 1-2 (1961).

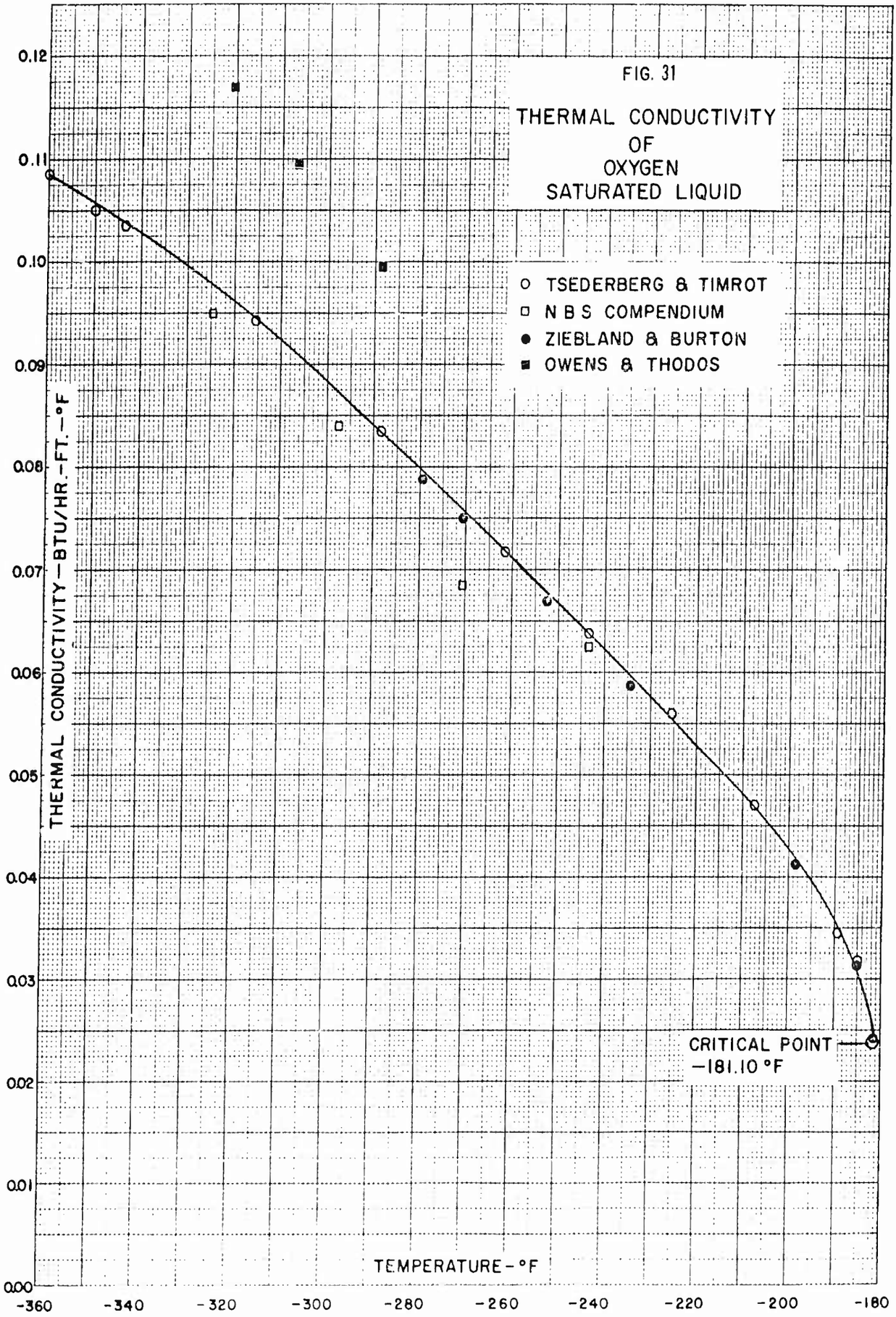
5. Tsederberg, N.V. and D. L. Timrot, "Experimental Determination of Thermal Conductivity of Liquid Oxygen", Zhur. Tekh. Fiz. 26, 1849-56 (1956).

6. Ziebland, H. and J.T.A. Burton, "The Thermal Conductivity of Liquid and Gaseous Oxygen", Brit. J. Appl. Phys. 6, 416 (1955).

The data calculated using the equations of Tsederberg and Timrot (5) were given primary weight in plotting the thermal conductivity of saturated liquid oxygen given in Figure 31. These equations were used to calculate values of the thermal conductivity over the range, -360°F to -181°F. Although the equations specifically exclude a transition range near the critical point, values of thermal conductivity in the range of -213° to -183°F were computed using the equation for the lower temperatures. Agreement with values from Ziebland and Burton (6) at the same temperatures was very good, although these values were not subsequently graphed. The values of thermal conductivity at other temperatures from Ziebland and Burton (6) which are graphed, show small negative deviations from the smoothed curve of not more than 2%. This source was not given primary weight since values were read from a graph. Data from the other two sources, Owens and Thodos (3), and the NBS Compendium (2) are plotted for

comparison only. The deviations occurring when the correlation of Owens and Thodos (3) is used for liquid oxygen are as high as 37.4%, according to the authors. The saturated liquid curve given in the NBS Compendium (2) is only an estimate. The values from references (2) and (3) were therefore accorded no weight in plotting. Hence, if these data points are ignored, the uncertainty of the smoothed curve becomes ± 2%.

The tabulated data are given in Table XI.



AF 33(616)-8287

J. Density of Oxygen

Sources of Data:

1. Byrne, R. and G. Thodos, "The P. V. T. Behavior of Diatomic Substances in their Gaseous and Liquid States", A. I. Ch. E. Journal 7, 185-189 (1961).

2. Dodge, B. F. and Davis, H. W., "Vapor Pressure of Liquid Oxygen and Nitrogen", J. Am. Chem. Soc. 49, 610-20 (1927).

3. Hilsenrath, J. et al, "Tables of Thermal Properties of Gases" NBS Cir. 564, 374-399 (1955).

4. Leiden Charts (Oxygen), Kamerlingh Onnes Laboratory, Dec. 1942.

5. Mathias, E. and H. K. Onnes, "Rectilinear Diameter for Oxygen", Commun. Phys. Lab. Univ. Leiden No. 117 (1911).

6. Scott, R. B., "The Density of Liquid Oxygen", NBS Rept. 6752, 1-2 (1961).

7. Van Itterbeek, A., Progress in Low Temperature Physics, Vol. I., North Publishing Company, Amsterdam, The Netherlands (1955) 366.

8. Van Itterbeek, A. and O. Verbeke, "Density of Liquid Oxygen as a Function of Pressure and Temperature", Cryogenics 1, 77 (1960).

Liquid and Vapor

The sources of data used in plotting the isobars for the gaseous oxygen densities as given in Figure 32 were taken from the Leiden Chart (4) and Hilsenrath et al (3), from the latter of which data points were calculated from a virial equation of state. The largest errors in these values, according to Hilsenrath et al (3), occur at low density due to fitting the second virial coefficient imperfectly, and may be as high as 3% of the deviation from ideality. However, over the range that this data was used 10 to 1500 PSIA, and -280°F to 116.3°F, the uncertainty in the density values should be well within ± 1%. Data from the Leiden Chart (4) were used with values from Hilsenrath (3) up to 1500 PSIA, and were used

exclusively at higher pressures, up to 4000 PSIA.

The values from both sources correlate very well; the deviation and data points about the isobars is very small, the uncertainty estimated to be within ± 1%.

The tabulated data are given in Table XII.

Saturated Liquid

The most recently experimental results are those of Van Itterbeek and Verbeke (8) who report measured values over the temperature range, -343.3 to -297.2°F. From these values, an equation for saturation density was given by these investigations, and this equation was used to compute values up to -195°F. According to Scott (6), the densities up to about 95°K (-288.7°F) are reliable to within 0.1%. This uncertainty increases with increasing temperature, perhaps reaching 0.5% at 125°K (-234.7°F). An increased uncertainty may be assumed at temperatures above 125°K. The data of Van Itterbeek (7) cover the range, -349.9° to -297.7°F. Primary weight in plotting the saturated liquid density of oxygen as shown in Fig. 33 was given to the values from both references (7) and (8) over the common temperature range, while at higher temperatures, the calculated and experimental values from reference (8) were given primary weight.

Although the values from Mathias and Onnes (5) are more precise than those of Van Itterbeek (7), they are not as recent, and were consequently given secondary weight in plotting the curve. The average deviation of the points of Mathias and Onnes (5) from the curve is approximately ± 1%. Points calculated from the reduced-state correlation of Byrne and Thodos (1) are also plotted, and according to these authors, the uncertainty in the oxygen values thus obtained averages about 0.9% with maximum values approaching 5%. The variation of data points about the smoothed curve is ± or less.

In summary, it is probable that the uncertainty of values obtained from the curve does not exceed ± 1%.

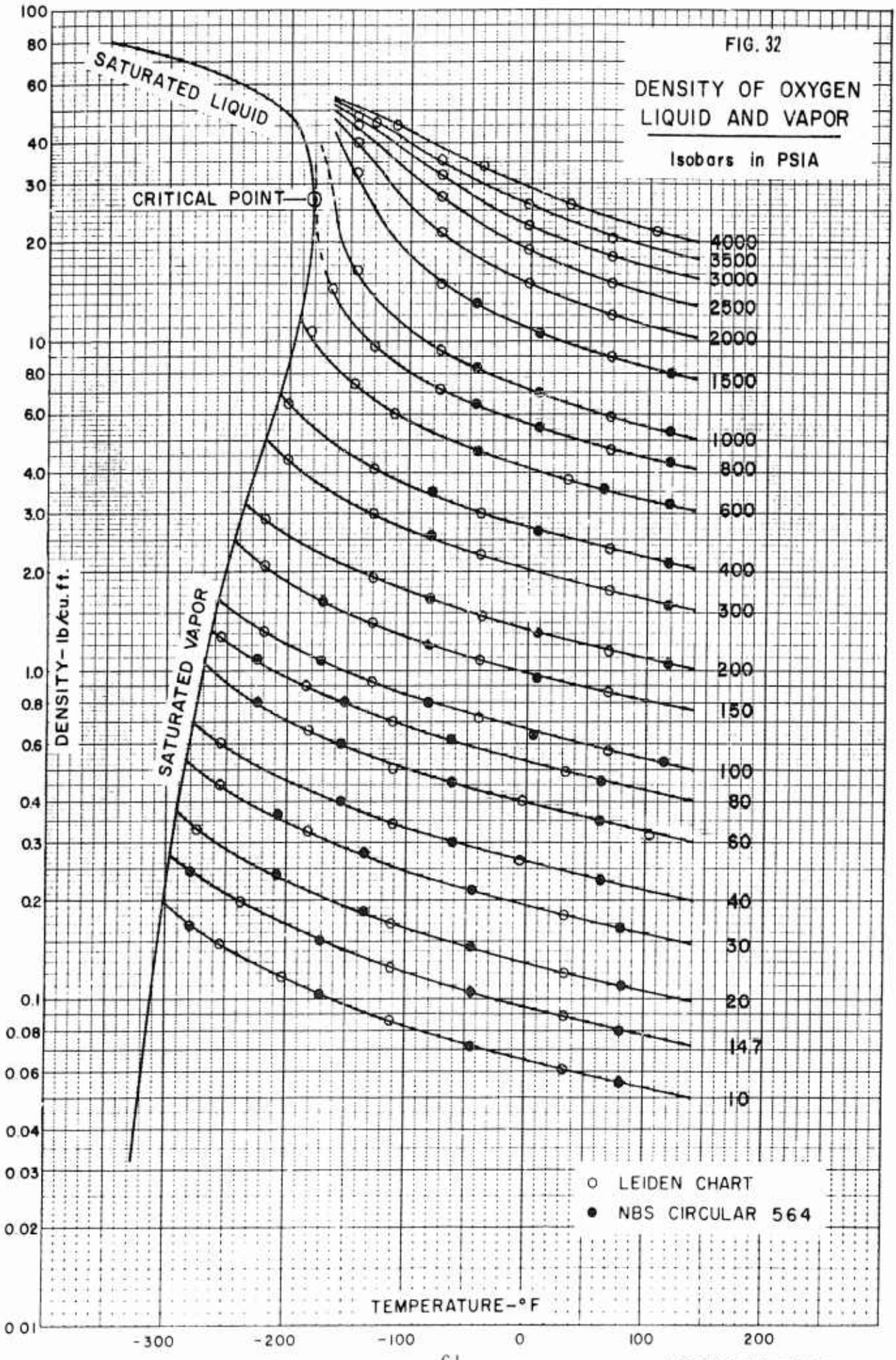
The tabulated data are given in Table XIII.

Saturated Vapor

The major data source used in plotting the saturated vapor curve given in Fig. 34 was the Leiden Chart (4) from which density values over the temperature range, -303.5 to -184°F, were plotted. At lower temperatures, -328.7 to -300°F, several series of density values at given pressures from Hilsenrath (3) were extrapolated to the saturation temperature, as determined from the vapor pressure of oxygen (2). Using these extrapolated points as a guide, the saturated vapor line was thus extended to the lower temperatures. The other data source used was the correlation of Byrne and Thodos (1) from which the values plotted covered the temperature range, -209° to -181.1°F. The average deviation of the values from experimental values is less than ± 1%.

All of the data sources were given equal weight in plotting the curve, since all the data appeared to be consistent. The deviation of data points about the curve is small in most cases less than 1%, although deviations of up to ± 4% are present.

The tabulated data are given in Table XIV.



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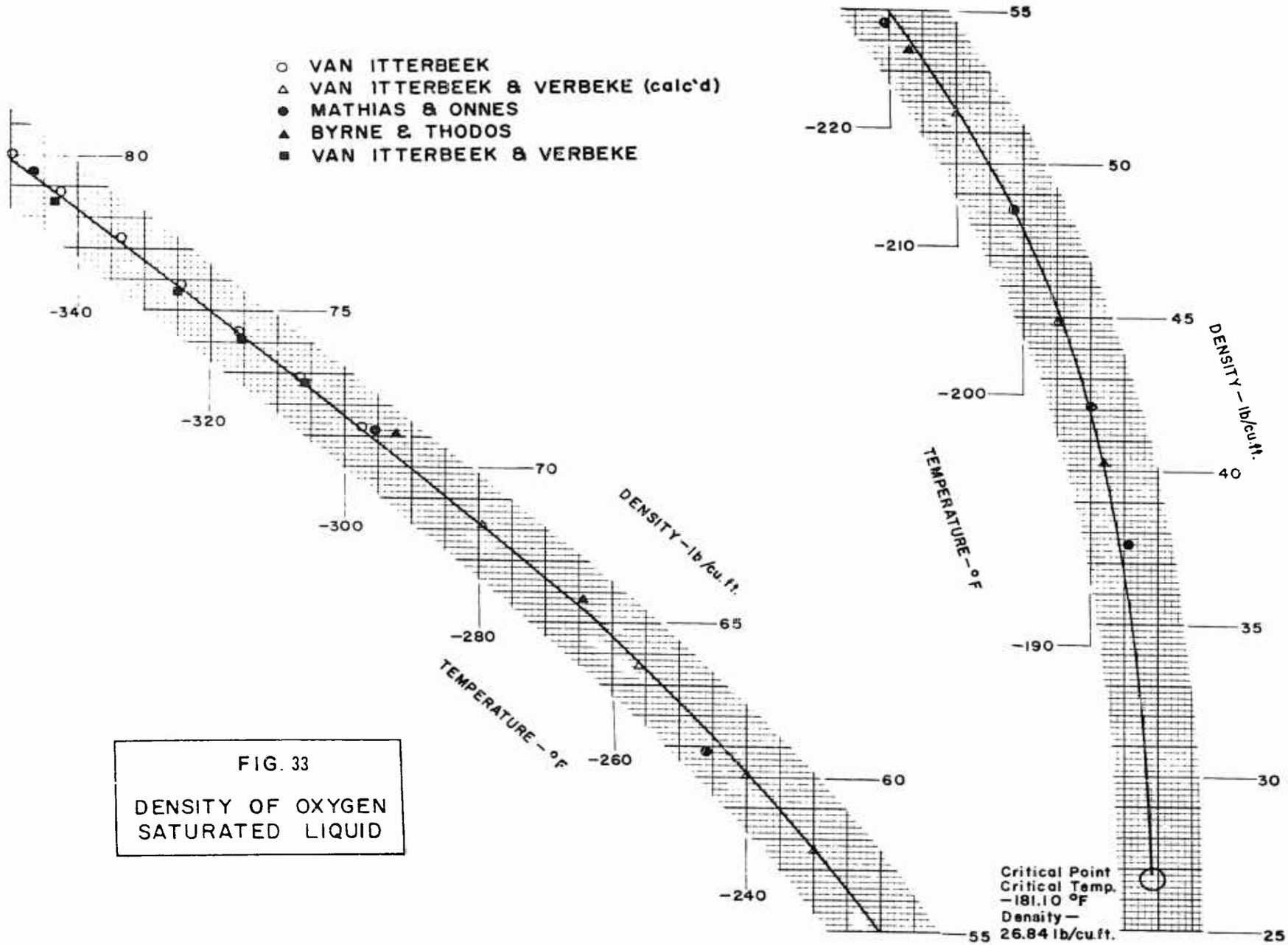
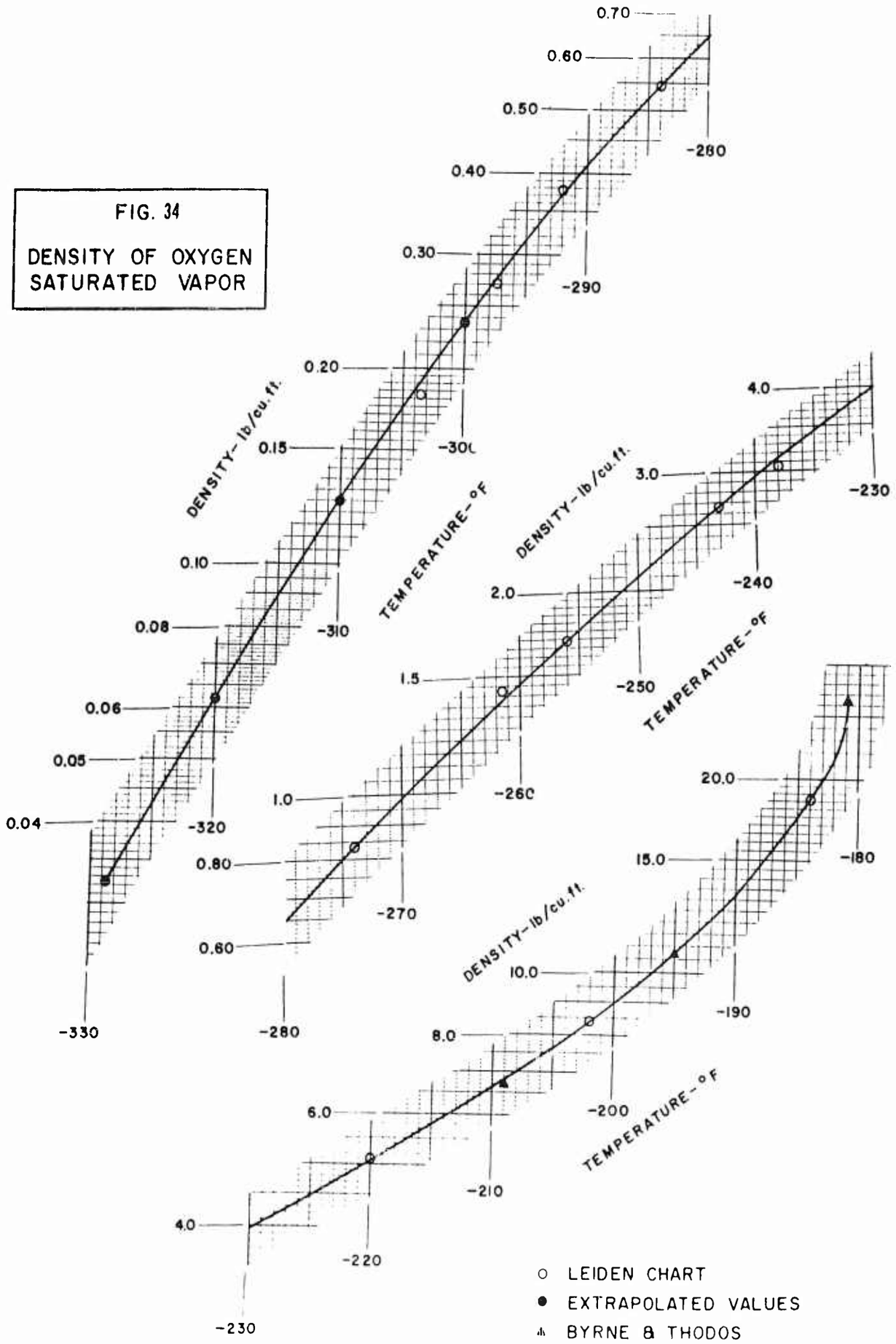


FIG. 33

DENSITY OF OXYGEN
SATURATED LIQUID

FIG. 34

DENSITY OF OXYGEN SATURATED VAPOR



K. Density of Nitrogen

Sources of Data:

1. Benedict, M., "Pressure, Volume, Temperature Properties of Nitrogen at High Density I.", J. Am. Chem. Soc. 59, 2224 (1937).

2. Byrne, R. and G. Thodos, "The P. V. T. Behavior of Diatomic Substances in their Gaseous and Liquid States", A. I. Ch. E. Journal 7, 185 (1961).

3. Hilsenrath, J. et al, "Tables of Thermal Properties of Gases", NBS Cir. 564, 323-327 (1955).

4. Johnson, V. J., "A Compendium of the Properties of Materials at Low Temperatures, (Phase I)", WADD TR-60-56, Oct., 1960, p. 1.004.

5. Leiden Charts (Nitrogen), Kamerlingh Onnes Laboratory, May, 1940.

6. Mathias, E., H. K. Onnes, and C. A. Crommelin, Leiden Comm. 14, No. 145C (1914).

Liquid and Vapor

Two data sources were used almost exclusively in plotting the gaseous density curves shown in Figure 35. These were the Leiden Charts (5) and NBS Circular 564 (3). Both sources furnished values over the entire pressure range, 10 to 1500 PSIA. Values from reference (5) were taken from a crossplot to insure accurate interpolation. Density values from reference (3) were computed directly from a virial equation of state. The parameters and constants were chosen so as to make the values most accurate at moderate and elevated temperatures, greater than 300°K. Hence, the results from reference (3) are less accurate at lower temperatures. Such values were not given primary weight in plotting the curves. Values from the high-pressure density determinations of Benedict (1) were included in plotting the 1500 PSIA isobar. These values were obtained from a crossplot of the Benedict data.

The data sources are in good agreement. The uncertainty in the values from reference (3) are very small at temperatures above 300°K, and, even at lower temperatures, are always less than 1% with the values used. In constructing the isobars near the cricital point, results from reference (5) were used exclusively, with the exception of the values from Benedict (1) for the 1500 PSIA isobar, since information from reference (3) about this region tended to be sparse and increasingly uncertain. Values obtained from this region will, however, tend to be more uncertain than values at higher temperatures and lower pressures. Because of the small spread of points about the curves, and the accuracy of the data used, there is confidence that the isobars are accurate to within ± 1%.

The tabulated data are given in Table XV.

Saturated Liquid (Figure 36)

Since the four data sources (2, 4, 5, 6) used in plotting the saturated liquid nitrogen density as shown on Figure 35 gave consistent results, no particular source was given special weight in drawing the smoothed curve. The values of Byrne and Thodos (2) were correlated as reduced-densities which the authors termed "accurate" This correlation was developed from nitrogen data. The data of Mathias, et al (6) is not recent but is precise and gives consistent density values. The data from reference (4) is actually that of:

(A) Gerold, E., Ann. Physik 65, 82-96 (1921)
(B) International Critical Tables, McGraw-Hill Book Co., New York (1927)
(C) Mathias, E. and Crommelin, C. A., Proc. Fourth Intern. Congress of Refrig. 1, 89-106 (1924)

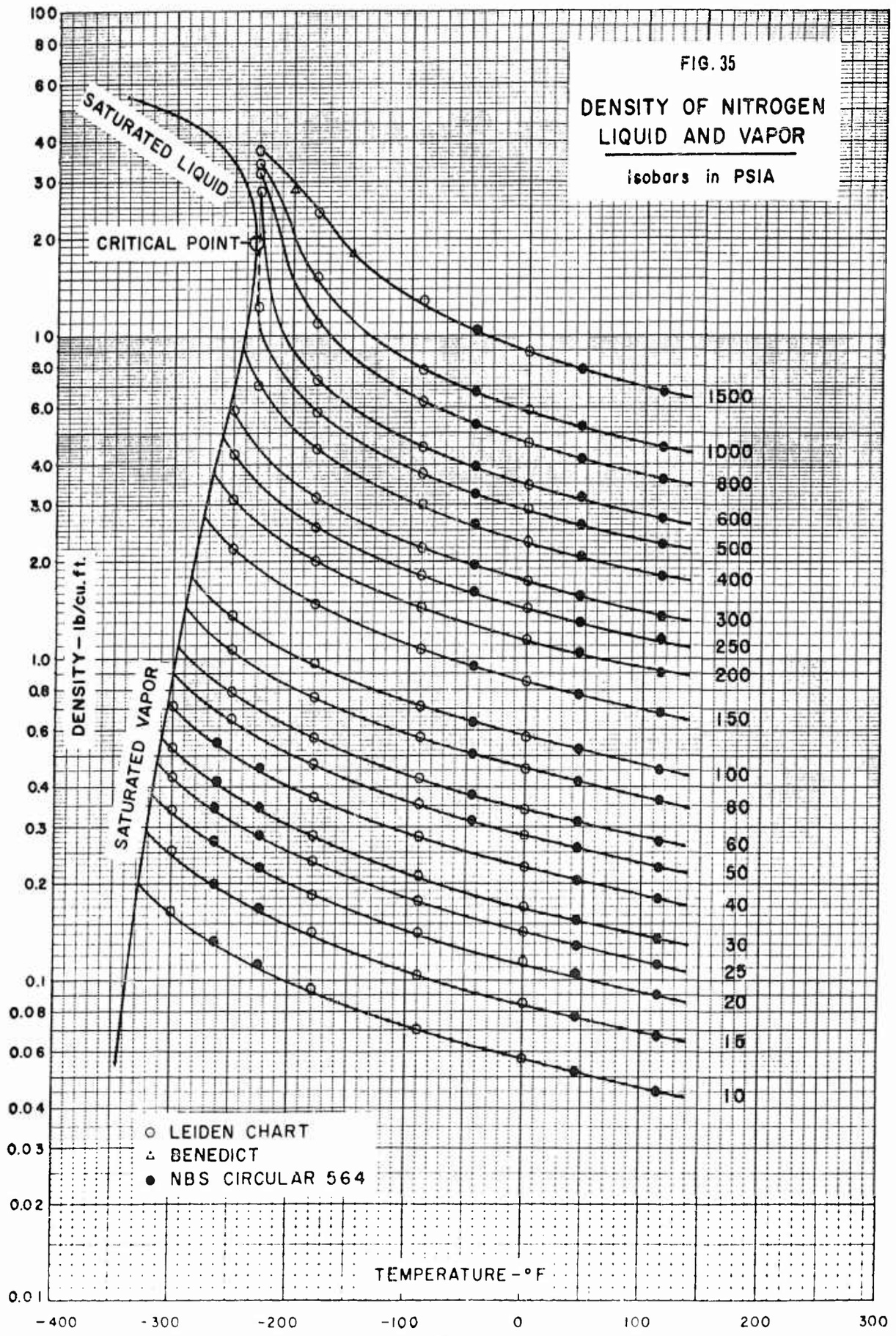
The values from the Leiden Chart (5) cover a smaller temperature range (-290° to -240°F) than results from the other sources. The data from all the sources cover the range, -343.2°F to -232.6°F. There is virtually no spread of points at all about the smoothed curve at lower temperatures; some deviation occurs near the critical point. The uncertainty in reading the smoothed plot should be well within ± 1% at temperatures between -343.2 and -243.9°F, but may reach ± 2% near the critical point.

The tabulated data are given in Table XVI.

Saturated Vapor (Figure 37)

The results from the Leiden Chart (5) and the NBS Compendium (4) were quite consistent and were given equal weight in plotting the density of saturated nitrogen vapor shown on Figure 37. The Leiden Chart (5) covered the range, -326° to -240.5°F; values from the NBS Compendium (4) were plotted over the range, -343.2° to -234.7°F. The tabulated reduced-density values of Byrne and Thodos (2) showed consistent deviations from these data (5) (4). They were included over the temperature range, -323.4° to -232.6°F.

The smoothed plot fits the points well to about -285°F. There is virtually no spread of points from references (5) and (4) at the lower temperatures, although values from reference (2) show deviations up to 4%. At higher temperatures, the number of points deviating from the curve increases, the deviation reaching maximums of ± 5%. Over the entire temperature range, the uncertainty in values obtained from the curve is probably 2 to 3%.



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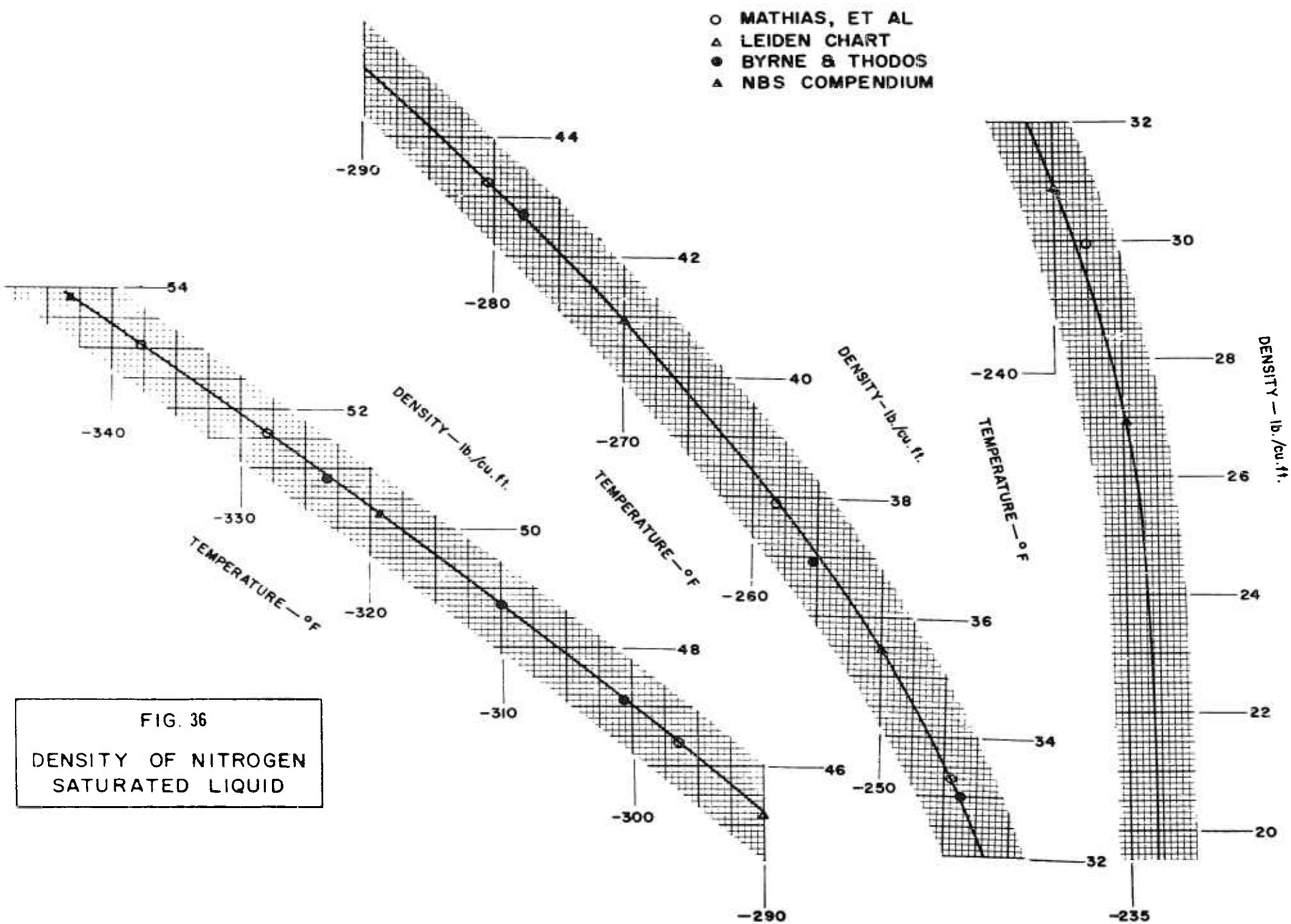

FIG. 36

DENSITY OF NITROGEN
SATURATED LIQUID

AF 33(616)-8287

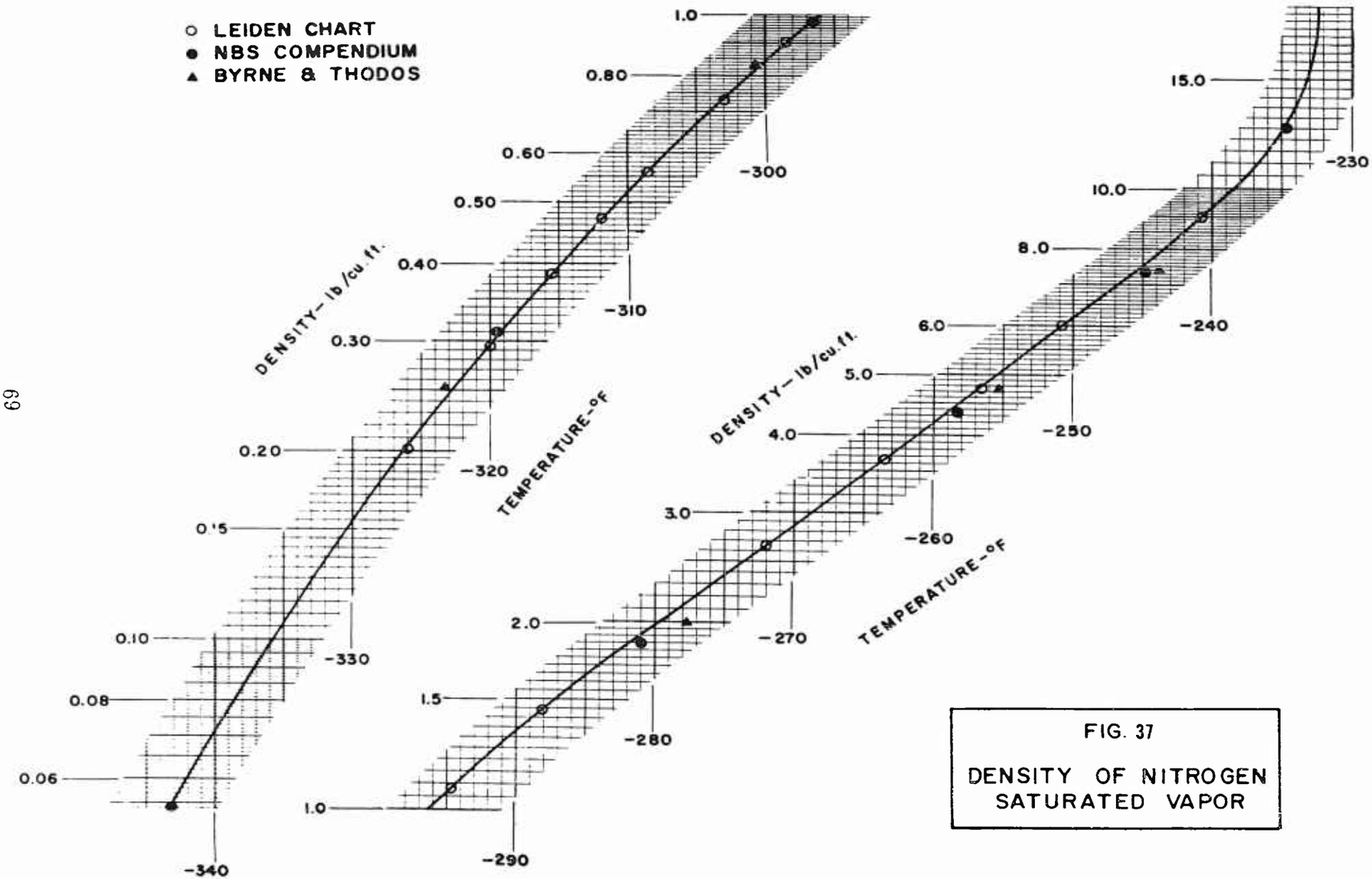

FIG. 37

DENSITY OF NITROGEN SATURATED VAPOR

L. Prandtl Number of Nitrogen

Sources of Data:

1. Deming, W.E., and L.E. Shupe, "Some Physical Properties of Compressed Gases. I. Nitrogen", Phys. Rev. 37, 638-54 (1931).

2. Hall, N.H. and W.E. Ibele, "Thermodynamic Properties of Air, Nitrogen, and Oxygen as Imperfect Gases", Univ. Minn. Inst. Technical Eng. Expt. Sta. Tech. Paper 85, (1951).

3. Hilsenrath, J. et al, "Tables of Thermal Properties of Gases", NBS Circ. 564, 331-333-359 (1955).

4. Johnson, V.J., "A Compendium of the Properties of Materials at Low Temperatures (Phase I)", WADD TR-60-56, Oct., 1960, p. 3.004 and 4.004.

The values of viscosity and thermal conductivity for the saturated liquid and saturated vapor curves, and for the isobars from 500 to 2000 PSIA, inclusive, were read from the viscosity and thermal conductivity graphs Figures 1 and 9 of this report. For the 200 and 300 PSIA isobars, interpolated values of viscosity and thermal conductivity from these graphs were used, except for the temperatures of -171.7 and -135.7°F at 200 PSIA, and the temperature range -207.7 to -99.7°F at 300 PSIA, where data from the NBS Compendium, 3.004 (4) were used. Values of thermal conductivity at constant temperature for various pressure values were read from the plot given in reference (4) and replotted as a curve of thermal conductivity vs. pressure with temperature as a parameter, enabling an accurate interpolation to be made. The Prandtl Number is shown in Figure 38.

For the saturated liquid curve, values of the specific heat were read from the graph, 4.004, of reference (4). This graph can be read with a high degree of precision, approximately, 0.2%. An extrapolation of values found in Hall and Ibele (2) to the saturation temperature was necessary to obtain specific heat values for the saturated vapor. The extrapolated values of specific heat become less reliable as the saturation temperature approaches the critical temperature. At 1 atm., values of specific heat for the calculated nitrogen Prandtl Numbers

were obtained from the data of 4.004 of reference (4) and from NBS Circular 564 (3). In addition, values of the Prandtl Number of nitrogen from reference (3) were plotted at 1 atm; these values were given primary weight, since they correlated well. The specific heat values for the 500 PSIA isobar were taken from three sources: at temperatures above 0°F, reference (3) was used; at lower temperatures (-200 to 0°F), a curve of specific heat vs. temperature was drawn from the series of values, and extrapolated. For the other isobars, specific heat values from reference (3) were most often used, although at lower temperatures some values were taken from references (2) and (4). Data of Deming and Shupe (1) were used to obtain the specific heat on the 2000 PSIA isobar. Obtaining values from reference (3) generally required a double interpolation (temperature and pressure). The data of reference (4) are probably most reliable, but the values of Hall and Ibele (2) are most precise.

It should be noted that the 300 and 1500 PSIA isobars are not plotted; values for the Prandtl numbers at these pressures are included in the tabulated of data, however. Both the saturated vapor and saturated liquid curves approach infinity as the temperature approaches the critical point. The reason for this is that at the critical point, the specific heat becomes infinite, while the viscosity and thermal conductivity both remain finite. Because of the lack of data available, the Prandtl Number for the saturated vapor (-320° to -270°F) and for the 200 PSIA isobar (-260° to -180°F) is likely to be most doubtful. The 14.7 and 200 PSIA isobars are drawn as a single line above -120°F, since the Prandtl Number for both isobars indicate that this is the best curve.

The crossing of the 1000 psia and 2000 psia isobars is indicated clearly by the calculations based on the data for the individual properties. However, the differences between these curves never exceed about 5%, which is within the accuracy resulting from the calculations. Thus this intersection may not be a physical fact.

The tabulated data are given in Table XVIII.

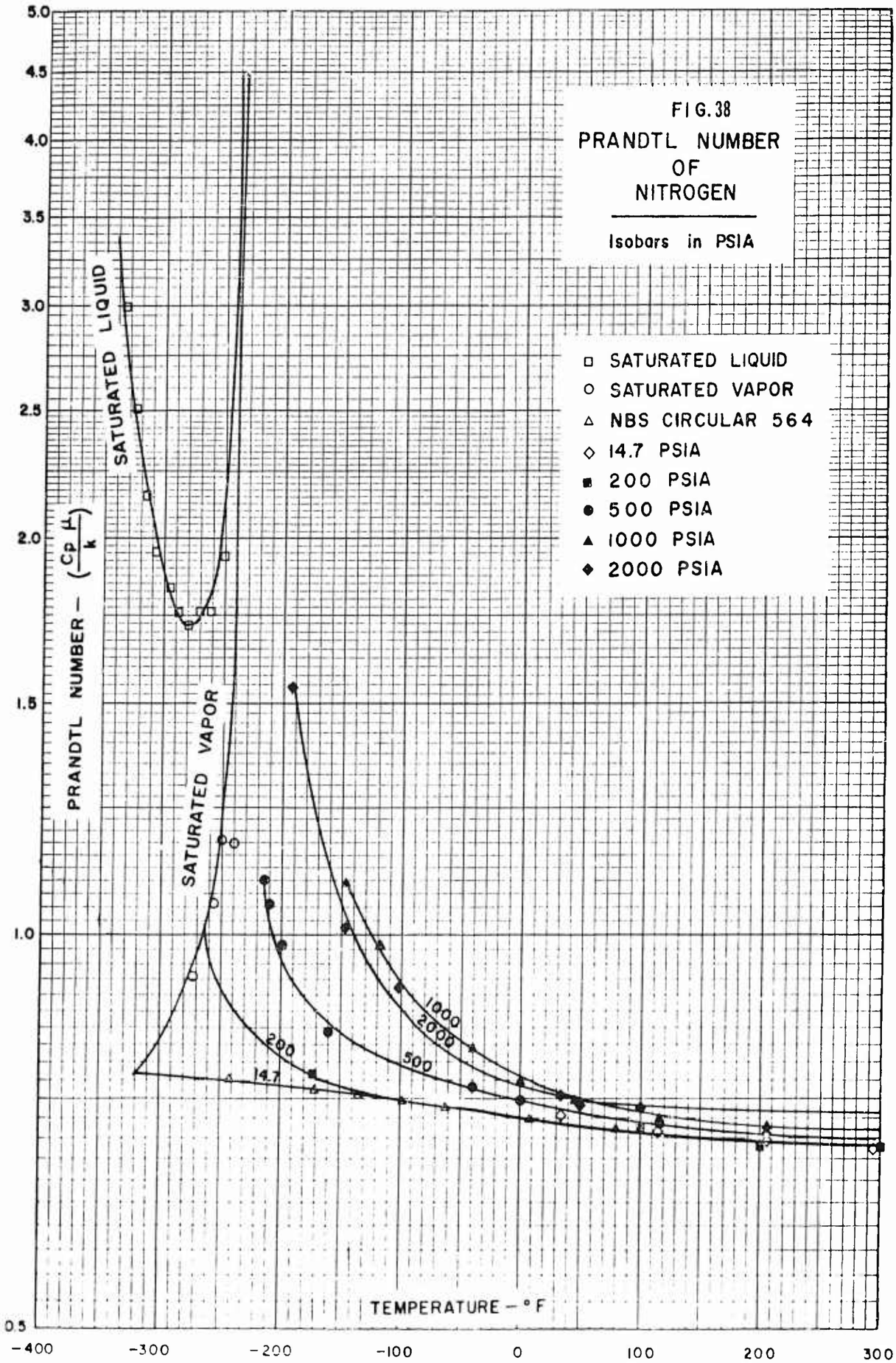
FIG. 38
PRANDTL NUMBER OF NITROGEN
Isobars in PSIA
SATURATED LIQUID
SATURATED VAPOR
NBS CIRCULAR 564
14.7 PSIA
200 PSIA
500 PSIA
1000 PSIA
2000 PSIA
PRANDTL NUMBER — $\left(\frac{Cp\,\mu}{k}\right)$
TEMPERATURE — °F
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
−400
−300
−200
−100
0
100
200
300
1000
2000
500
200
14.7

M. Prandtl Number of Oxygen

Source of Data:

1. Hall, N. H. and Ibele, W. E., "Thermodynamic Properties of Air, Nitrogen, and Oxygen as Imperfect Gases", Univ. Minn. Inst. Technical Eng. Expt. Sta. Tech. Paper 85 (1957).

2. Hilsenrath, J. et al, "Tables of Thermal Properties of Gases", NBS Cir. 564, 402, 426 (1955).

Prandtl Number values were computed from values of specific heat, viscosity and thermal conductivity in all cases except for values at 14.7 PSIA. Values of viscosity and thermal conductivity for the isobars (14.7 to 2000 PSIA) were read from the graphs of the viscosity and thermal conductivity of gaseous oxygen presented as Figures 2 and 10 of this report. The values for 200 and 400 PSIA were determined by linear interpolation between 14.7 and 500 PSIA. The uncertainty in the interpolated values increases with increasing nonlinearity of the isobars on the viscosity and thermal conductivity and hence increases with decreasing temperature. Values of viscosity and thermal conductivity for the saturated vapor were also read from these graphs. For the saturated liquid, the graphs of thermal conductivity and viscosity for liquefied oxygen (saturated), Figures 4 and 11 of this report, were read.

The specific heat values for the saturated liquid were determined by extrapolating graphically a series of specific heat values near the saturation curve at given pressures. This was done with the aid of the data of Hall and Ibele (1). Specific heat values for the saturated vapor and all of the isobars except 14.7 PSIA were obtained by differencing these data. For the isobar of 14.7 PSIA, specific heat values from NBS Circular 564 (2) were used over the range, +116.3 to +296.3°F. From -279.7 to +98.3°F, values of the Prandtl Number at 1 atm were used from reference (1) directly.

Because the Prandtl Number values at 14.7 PSIA correlated so well, they were used as a guide to the shape of the saturated vapor curve. The 1 atm isobar was extrapolated slightly to the saturation temperature, determining a point on the saturated vapor curve. This curve was then estimated from -300 to -210°F,

using values near the latter temperature. The 200 PSIA isobar did not correlate very well, so that its extrapolation to the saturation temperature did not provide a meaningful check on the shape of the saturation curve. The 400 PSIA isobar could be more accurately plotted, and hence its extrapolation was more meaningful. However, the saturation temperature at 400 PSIA occurs on a part of the saturation curve which is relatively well-defined. Consequently, the most doubtful regions of the curve are (a) the saturated vapor line from -300 to -210°F, and (b) the 200 PSIA isobar from -230 to -160°F.

The resulting graph of the Prandtl Number of oxygen is presented in Figure 39 and the tabulated data are given in Table XIX.

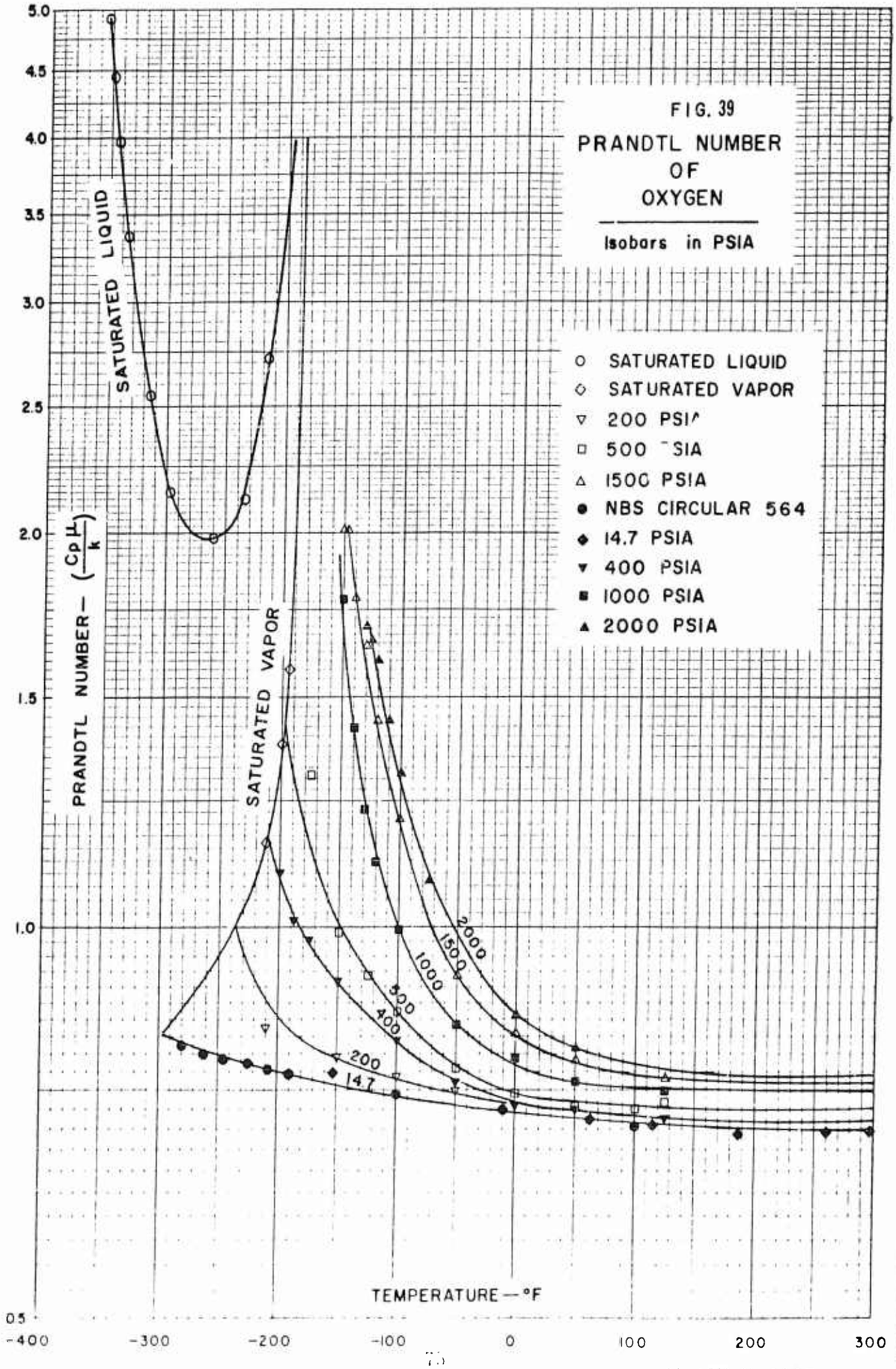
FIG. 39
PRANDTL NUMBER OF OXYGEN
Isobars in PSIA
SATURATED LIQUID
SATURATED VAPOR
200 PSIA
500 PSIA
1500 PSIA
NBS CIRCULAR 564
14.7 PSIA
400 PSIA
1000 PSIA
2000 PSIA
PRANDTL NUMBER — $(\frac{Cp\mu}{k})$
SATURATED LIQUID
SATURATED VAPOR
2000
1500
1000
500
400
200
14.7
TEMPERATURE — °F
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
-400
-300
-200
-100
0
100
200
300

IV. Conclusions and Recommendations

The charts of thermodynamic data presented in this report represent a complete and consistent review of the results of investigators who have published prior to July, 1961. Although data were selected on the basis of consistency and adherence to known physical relationship, the selection was largely a matter of judgement. Those who wish to examine this judgement will find a complete bibliography in Section V, and a tabulation of the data in the Appendix.

The data reported cover a rather narrow range of temperature. It is recommended that similar studies be undertaken by the Air Force to include the solidus region and the superheated gas region to 4000°F.

APPENDIX

V. BIBLIOGRAPHY

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TABLE I.

VISCOSITY OF NITROGEN

(1) Michels and Gibson			(2) Kestin and Leidenfrost		
T, °F	P, psia	μ, lb/ft. hr.	T, °F	P, int. atm.	μ, cp.
77	2,000	0.0508	19.94	62.07	0.018789
	4,000	0.0629	19.93	48.69	0.018447
	6,000	0.0750	19.92	34.82	0.018132
	8,000	0.0883	19.98	20.48	0.017874
	10,000	0.1004	20.00	18.04	0.017825
122	2,000	0.0520	20.74	14.59	0.017802
	4,000	0.0629	20.14	11.17	0.017713
	6,000	0.0726	20.48	7.79	0.017682
	8,000	0.0847	20.20	4.38	0.017625
	10,000	0.0956	20.58	1.00	0.017604
167	2,000	0.0545	20.15	0.687	0.017579
	4,000	0.0641	20.04	0.385	0.017570
	6,000	0.0762	20.01	0.139	0.017549
	8,000	0.0823	24.99	69.04	0.019176
	10,000	0.0932	24.98	55.50	0.018812
			25.00	41.86	0.018491
			25.06	28.21	0.018227
			25.00	14.60	0.018000
			25.00	7.80	0.017894
			25.00	0.991	0.017807

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TABLE I. (Continued)

VISCOSITY OF NITROGEN

(3) Baron, Roof, and Wells			(4) Ross and Brown		
T, °F	P, psia	μ, lb/ft hr.	T, °F	P, psig	μ, lb/ft. hr.
125	100	0.0450	77	500	0.04477
	500	0.0461		675	0.04501
	1,000	0.0479		1,000	0.04605
	2,000	0.0524		1,500	0.04859
	3,000	0.0576		2,000	0.05046
	4,000	0.0632		3,000	0.05622
	5,000	0.0686		4,000	0.06205
	6,000	0.0743		5,000	0.06921
	7,000	0 0800		6,000	0.07509
	8,000	0.0857		8,000	0.08794
225	100	0.0516		10,000	0.10048
	500	0.0525	32	5,000	0.04179
	1,000	0.0538		1,000	0.04417
	2,000	0.0572		1,500	0.04600
	3,000	0.0613		2,000	0.04925
	4,000	0.0657		3,000	0.05585
	5,000	0.0700		4,000	0.06302
	6,000	0.0746		5,000	0.07074
	7,000	0.0794		6,000	0.07761
	8,000	0.0840		8,000	0.09215
275	100	0.0542		10,000	0.10701
	500	0.0552	-13.2	500	0.03918
	1,000	0.0564		1,000	0.04194

TABLE I. (Continued)

VISCOSITY OF NITROGEN

(3) Baron, Roof, and Wells			(4) Ross and Brown		
T, °F	P, psia	μ, lb/ft. hr.	T, °F	P, psig	μ, lb/ft. hr.
	2,000	0.0596		1,500	0.04399
	3,000	0.0633		2,000	0.04770
	4,000	0.0672		3,000	0.05597
	5,000	0.0713		4,000	0.06357
	6,000	0.0756		5,000	0.07214
	7,000	0.0800		6,000	0.08056
	8,000	0.0842		8,000	0.09694
				10,000	0.11333
			-57.6	500	0.03695
				1,000	0.04044
				1,500	0.04281
				2,000	0.04680
				3,000	0.05636
				4,000	0.06563
				5,000	0.07461
				6,000	0.08405
				8,000	0.10232
				10,000	0.12100

TABLE II.

VISCOSITY OF OXYGEN

Johnston and McCloskey

1 atm.

T, °F	μ, lb/ft. hr.
-297.7	.01672
-279.7	.01857
-261.7	.02040
-243.7	.02218
-225.7	.02418
-207.7	.02567
-189.7	.02738
-171.7	.02909
-153.7	.03078
-135.7	.03244
-117.7	.03409
- 99.7	.03571
- 81.7	.03729
- 63.7	.03883
- 45.7	.04032
- 27.7	.04181
- 9.7	.04323
+ 8.3	.04466
+ 26.3	.04604
44.3	.04739
62.3	.04877
80.3	.05011

Hilsenrath, Touloukian

o = 01919 cp. =.04644 lb/ft. hr.

T, °F	μ, lb/ft. hr.
-280	.01881
-100	.03596
80	.04993
260	.06184
440	.07242
620	.08211

Kiyama and Makita

T, °F	psia / atm	14.7 / 1	294 / 20	588 / 40	881 / 60	1178 / 80	1470 / 100
77		.0489	.0523	.0547	.0576	.0605	(.0641)
122		.0532	.0552	.0571	.0600	.0627	(.0658)
212		.0593	.0607	.0627	.0646	.0670	(.0697)
302		.0649	.0658	.0673	.0687	.0707	(.0728)

TABLE II. (Continued)

VISCOSITY OF OXYGEN

Glaser and Gebhardt			Kestin and Leidenfrost			Luker and Johnson		
T, °F	P, psia	μ, lb/ft. hr.	T, °F	P, psia	μ, lb/ft. hr.	T, °F	P, psia	μ, lb/ft. hr.
57	147	0.0477	68	315	0.0501	475	1,445	0.0795
	735	0.0489		265	0.0500	386	1,439	0.0739
	1,470	0.0515		214	0.0498	430	1,439	0.0765
	2,200	0.0576		164	0.0496	133	1,472	0.0639
	2,500	0.0600		114	0.0495	176	1,466	0.0658
191	147	0.0547		64.5	0.0493	396	772	0.0717
	735	0.0552		14.4	0.0492	470	763	0.0760
	1,470	0.0571		9.31	0.0492	378	1,886	0.0734
	2,200	0.0598		1.94	0.0491	446	1,882	0.0811
	2,570	0.0620	77	762	0.0525	496	1,876	0.0801
	2,790	0.0641		614	0.0519			
				415	0.0511			
				215	0.0505			
				115	0.0502			
				14.7	0.0500			

TABLE II. (Continued)

VISCOSITY OF OXYGEN

Brebach and Thodos

μ, lb/ft. hr. at Temperatures Noted

P, psia	400° F	250° F	150° F	100° F	0° F	-50° F	-100° F	-150° F	-200° F
14.7	0.0698	0.0607	0.0547	0.0512	0.0440	0.0400	0.0345	0.0318	0.0265
500	0.0703	0.0614	0.0553	0.0523	0.0452	0.0410	0.0380	0.0354	0.0335
1,000	0.0715	0.0626	0.0564	0.0540	0.0482	0.0446	0.0419	0.0434	0.160
1,500	0.0732	0.0643	0.0582	0.0570	0.0518	0.0507	0.0511	0.0683	0.178
2,000	0.0750	0.0668	0.0612	0.0601	0.0565	0.0570	0.0642	0.0892	0.214
3,000	0.0770	0.0703	0.0671	0.0654	0.0665	0.0731	0.0904	0.125	
4,000	0.0810	0.0750	0.0748	0.0733	0.0785	0.0890	0.113	0.149	
6,000	0.0864	0.0835	0.0842	0.0868	0.1052	0.120	0.150	0.195	
8,000	0.0940	0.0954	0.0983	0.1010	0.1250	0.147	0.190	0.238	
10,000	0.1024	0.1047	0.1100	0.1200	0.1490	0.174	0.217	0.274	

TABLE III.

VISCOSITY OF AIR

H. L. Johnston and K. E. McCloskey

T, °K	T, °F	μ, lb/ft. hr.
90	-297.7	.01558
100	-279.7	.01724
110	-261.7	.01888
120	-243.7	.02047
130	225.7	.02204
140	207.7	.02360
150	189.7	.02510
160	171.7	.02663
170	153.7	.02810
180	135.7	.02954
190	117.7	.03096
200	99.7	.03234
210	81.7	.03371
220	63.7	.03504
230	45.7	.03637
240	27.7	.03765
250	- 9.7	.03891
260	+ 8.3	.04134
	26.3	.04250
	44.3	.04365
	62.3	.04443
	80.3	.04479

J. Hilsenrath and Y. S. Touloukian

T, °R	T, °F	μ/μ_o	μ
180	-280	.4038	.01675
360	-100	.7742	.03215
540	80	1.076	.0446
720	260	1.332	.0553
900	440	1.556	.0646

μ_o = .04151 lb/ft. hr.

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TABLE III. (Continued)

VISCOSITY OF AIR

W. J. Brebach and G. Thodos

P, psia	T=400°F	T=200°F	T=100°F	T=0°F	T=-100°F	T=-150°F	T=-200°F	T=-250°F
14.7	0.0634	0.0528	0.0461	0.0398	0.0326	0.0288	0.0249	0.0204
500	0.0644	0.0537	0.0475	0.0412	0.0351	0.0312	0.0312	0.0233
1,000	0.0654	0.0548	0.0495	0.0441	0.0394	0.0384	0.0610	0.173
1,500	0.0668	0.0566	0.0519	0.0475	0.0461	0.0456	0.0888	
2,000	0.0682	0.0585	0.0547	0.0514	0.0528	0.0671	0.1080	
3,000	0.0706	0.0614	0.0590	0.0586	0.0695	0.0902	0.1368	
4,000	0.0744	0.0643	0.0663	0.0682	0.0873	0.112	0.1648	
6,000	0.0788	0.0758	0.0768	0.0865	0.1128	0.151		
8,000	0.0865	0.0888	0.0909	0.1058	0.1462	0.188		
10,000	0.0922	0.0960	0.1046	0.1268	0.1750	0.223		

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TABLE III. (Continued)

VISCOSITY OF AIR

J. Kestin and W. Leidenfrost

P, psia	μ, lb/ft. hr.
913.8	0.0471
708.8	0.0462
514.1	0.0455
314.6	0.0448
265.0	0.0447
214.8	0.0445
164.9	0.0444
114.5	0.0443
64.5	0.0442
14.7	0.0441
10.5	0.0441
6.76	0.0440
1.93	0.0440
1,015	0.0481
766.9	0.0470
516.3	0.0461
264.7	0.0453
14.7	0.0447

TABLE III. (Continued)

VISCOSITY OF AIR

Glaser and Gebhardt

T. C	T. °F	μ at P = 14.7	34 atm P=500	68 atm P=1,000	102 atm P = 1,500	136 atm P=2,000	204 atm P = 3,000	272 atm P=4,000	408 atm P = 6,000
- 2	28.4	17 .0420			19.7 .0488		23.4 .0566		33.8 .0818
14	57.2	17.8 .0440			19.3 .0479		22.7 .0550		31.6 .0765
28	83	18 .0446			19.6 .0486		22.3 .0540		29.2 .0707
65	149	19.0 .0472			21.1 .0523		23.3 .0564		30.1 .0739
88	190	19.8 .0491			21.9 .0543		24.0 .0581		31.7 .0758
120	248	21.2 .0526			23 .0570		26.0 .0629		34.0 .0824
150	302	22.7 .0563			25 .0620		27.2 .0658		36.0 .0872
180	356	24.5 .0608			26.3 .0653		29.4 .0712		37.4 .0905

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TABLE IV.

VISCOSITY OF SATURATED LIQUID OXYGEN

T, °F	Visc., #/ft. hr.	Source of Data
-361.8	2.11	Rudenko and Shubnikow
-360.9	1.87	Rudenko and Shubnikow
-356.9	1.54	Rudenko and Shubnikow
-352.2	1.53	Rudenko and Shubnikow
-345.4	1.15	Rudenko and Shubnikow
-336.1	0.817	Van Itterbeek and Van Paemel
-331.4	0.816	Van Itterbeek and Van Paemel
-329.6	0.782	Rudenko and Shubnikow
-328.8	0.796	Van Itterbeek and Van Paemel
-326.6	0.753	Van Itterbeek and Van Paemel
-315.7	0.605	Rudenko and Shubnikow
-314.4	0.600	Van Itterbeek and Van Paemel
-309.3	0.547	Van Itterbeek and Van Paemel
-303.7	0.506	Van Itterbeek and Van Paemel
-297.3	0.457	Van Itterbeek and Van Paemel
-259.9	0.298	Rudenko
-233.3	0.266	Rudenko
-225.7	0.197	Brebach and Thodos (Reduced Plot)
-214.5	0.167	Brebach and Thodos
-210.9	0.242	Rudenko
-209.0	0.152	Brebach and Thodos
-203.4	0.140	Brebach and Thodos
-197.8	0.129	Brebach and Thodos
-197.8	0.237	Rudenko
-192.2	0.114	Brebach and Thodos
-186.7	0.0986	Brebach and Thodos
-182.3	0.218	Rudenko

TABLE V.

VISCOSITY OF SATURATED LIQUID NITROGEN

T, °F	Visc., #/ft. hr.	Source of Data
-344.6	0.704	Van Itterbeek and Van Paemel
-343.8	0.702	Van Itterbeek and Van Paemel
-343.7	0.687	Compendium, 10.004
-342.9	0.687	Van Itterbeek and Van Paemel
-340	0.617	Brebach and Thodos (Residual Plot)
-339.7	0.622	Compendium
-335.1	0.559	Van Itterbeek and Van Paemel
-334.8	0.552	Brebach and Thodos (Figure 7)
-331.1	0.506	Van Itterbeek and Van Paemel
-329.7	0.477	Compendium
-325	0.411	Brebach and Thodos (Residual Plot)
-323.4	0.405	Brebach and Thodos (Figure 7)
-321.7	0.399	Van Itterbeek and Van Paemel
-320.6	0.382	Van Itterbeek and Van Paemel
-319.7	0.370	Compendium
-310	0.293	Brebach and Thodos (Residual Plot)
-309.7	0.305	Compendium
-300.7	0.283	Brebach and Thodos (Figure 7)
-299.7	0.261	Compendium
-295	0.244	Brebach and Thodos (Residual Plot)
-289.7	0.227	Compendium
-280	0.198	Brebach and Thodos (Residual Plot)
-279.7	0.206	Compendium
-277.9	0.203	Brebach and Thodos (Figure 7)
-269.7	0.189	Compendium
-265	0.166	Brebach and Thodos (Residual Plot)
-259.7	0.179	Compendium
-255.3	0.177	Brebach and Thodos (Figure 7)
-255	0.121	Brebach and Thodos (Residual Plot)
-250	0.102	Brebach and Thodos (Residual Plot)

TABLE V. (Continued)

VISCOSITY OF SATURATED LIQUID NITROGEN

T, °F	Visc., #/ft. hr.	Source of Data
-245	0.0900	Brebach and Thodos (Residual Plot)
-235	0.0643	Brebach and Thodos (Residual Plot)
-232.6	0.0442	Brebach and Thodos (Residual Plot)

References

1) Brebach and Thodos, IEC 50, 1095 (1958)

2) NBS Compendium, 10.004 (based on data of:

   A) Rudenko, N. S., J. Exptl. Theoret. Phys. (U.S.S.R.) 9, 1078-80 (1939)

   B) Rudenko, N. S., and Shubnikow, L. V., Phys. Zeit. Sowjetunion 6, 470-7 (1934).)

3) Van Itterbeek, A., and Van Paemel, C., Physica, 8, 133 (1941).

TABLE VI.

CALCULATED VISCOSITY OF LIQUID N_2-O_2 MIXTURES

Mole % Oxygen	T, (°F)	Viscosity of Mixture (#/ft. hr.)
75	-340	0.868
	-320	0.575
	-300	0.412
	-280	0.318
	-260	0.257
50	-340	0.776
	-320	0.507
	-300	0.353
	-280	0.272
	-260	0.216
25	-340	0.694
	-320	0.436
	-300	0.303
	-280	0.232
	-260	0.181

Equation used: $\log \mu_{mix} = X_1 \log \mu_1 + X_2 \log \mu_2$

TABLE VII.

PHASE RELATIONS IN THE OXYGEN-NITROGEN SYSTEM

Original Data of Dodge and Dunbar

T, °K	P, atm	x_{O_2}	y_{O_2}	T, °K	P, atm	x_{O_2}	y_{O_2}	T, °K	P, atm	x_{O_2}	y_{O_2}
76 79	0.5965	.4915	.1662	99.93	2.729	.9500	.8691	110.05	12.651	.2018	.1161
77.36	0.8712	.1586	.0459	99.94	2.903	.9299	.8135	110.05	13.663	.0955	.0537
90.53	1.174	.9458	.8264	99.93	3.022	.9005	.7545	119.91	11.850	.8798	.7812
90.54	1.360	.8900	.6908	99.93	3.256	.8640	.6871	119.91	12.880	.8082	.6763
90.49	1.551	.8241	.5640	100.00	3.452	.8209	.6106	119.95	14.505	.6910	.5404
90.54	1.559	.8212	.5592	99.92	3.845	.7488	.5092	119.92	15.952	.5889	.4378
90.60	1.586	.8060	.5368	99.93	4.760	.5752	.3334	119.88	18.068	.4474	.3154
90.50	1.808	.7287	.4341	99.98	5.043	.5125	.2871	119.88	18.939	.3751	.2585
90.40	2.145	.6097	.3158	99.93	5.623	.4103	.2148	119.91	21.482	.2100	.1414
90.34	2.302	.5511	.2712	99.94	5.841	.3624	.1837	119.90	22.981	.1162	.0789
90.50	2.401	.5043	.2413	99.92	6.640	.1944	.0923	124.93	15.531	.8907	.7976
90.46	2.467	.4939	.2364	99.93	7.180	.0914	.0422	124.95	16.857	.8050	.6905
90.46	2.501	.4694	.2192	110.03	6.033	.9348	.8483	125.06	20.450	.5963	.4629
90.70	2.799	.3521	.1502	110.11	6.606	.8734	.7374	124.95	22.992	.4592	---
90.78	3.262	.1626	.0634	110.04	7.286	.7983	.6250	124.98	24.298	.3775	.2805
				110.06	9.231	.5831	.3856	124.93	27.349	.2172	.1614
				110.03	10.734	.4192	.2564	124.96	29.332	.1200	.0911
				110.04	11.136	.3691	.2213				

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TABLE VII. (Continued)

Vapor Pressures Calculated from Dodge and Dunbar

Vapor Pressure at Liquid Composition, x_{O_2}, Noted, psia

T, °F	x = o	x=0.10	x=0.20	x=0.30	x=0.40	x=0.50	x=0.60	x=0.70	x=0.80	x=0.90	x=1.00
-330	7.45	6.95	6.43	5.87	5.30	4.70	4.07	3.41	2.74	2.03	1.30
-320	15.2	14.18	13.12	12.01	10.87	9.68	8.45	7.18	5.87	4.52	3.12
-310	27.5	25.67	23.78	21.83	19.82	17.76	15.43	13.45	11.21	8.92	6.56
-300	46.75	43.66	40.49	37.25	33.94	30.55	27.09	23.55	19.94	16.26	12.5
-290	74.0	69.19	64.29	59.31	54.24	49.08	43.84	38.51	33.09	27.59	22.0
-280	112	104.8	97.59	90.23	82.79	75.27	67.65	59.95	52.15	44.27	36.3
-270	162	151.7	141.3	130.8	120.3	109.8	99.22	88.59	77.91	67.18	56.4
-260	225	210.8	196.7	182.6	168.5	154.4	140.3	126.3	112.2	98.09	84.0
-250	305	285.3	266.2	247.4	228.9	210.7	192.6	174.6	156.5	138.5	120
-240	405	377.0	350.8	325.9	302.2	279.2	256.8	234.5	212.6	189.4	166

TABLE VII. (Continued)

PHASE RELATIONS IN THE OXYGEN-NITROGEN SYSTEM

Calculations from Dodge and Dunbar Equation

T °F											
	K_{O_2}										
x =	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
-330	.252	.2597	.2696	.2824	.2993	.3221	.3543	.4023	.4803	.6272	1.0
-320	.257	.2661	.2774	.2920	.3109	.3361	.3712	.4225	.5042	.6524	
-310	.274	.2843	.2972	.3135	.3344	.3620	.3998	.4542	.5385	.6850	
-300	.340	.3529	.3687	.388	.4130	.4448	.4870	.5451	.6295	.7623	
-290	.398	.4122	.4294	.4506	.4769	.5102	.5534	.6110	.6912	.8094	
-280	.445	.4591	.4763	.4975	.5236	.5565	.5986	.6538	.7290	.8362	
-270	.496	.5088	.5247	.5444	.5690	.5999	.6394	.6910	.7602	.8569	
-260	.555	.5646	.5785	.5936	.6148	.6420	.6773	.7237	.7861	.8730	
-250	.625	.6289	.6365	.6483	.6651	.6881	.7189	.7601	.8157	.8919	
-240	.714	.7056	.7029	.7062	.7161	.7332	.7589	.7949	.8441	.9104	
	K_{N_2}										
-330	1.0	1.082	1.183	1.308	1.467	1.678	1.969	2.395	3.079	4.355	7.576
-320		1.082	1.181	1.303	1.459	1.664	1.943	2.347	2.983	4.129	6.803
-310		1.080	1.176	1.294	1.444	1.638	1.900	2.273	2.846	3.835	5.952
-300		1.072	1.158	1.262	1.391	1.555	1.770	2.062	2.482	3.140	4.310
-290		1.065	1.143	1.235	1.349	1.490	1.670	1.908	2.235	2.715	3.484
-280		1.060	1.131	1.215	1.318	1.444	1.602	1.808	2.084	2.475	3.067
-270		1.055	1.119	1.195	1.287	1.400	1.541	1.721	1.959	2.288	2.770
-260		1.048	1.108	1.174	1.257	1.358	1.484	1.645	1.856	2.143	2.558
-250		1.041	1.091	1.151	1.223	1.312	1.422	1.560	1.737	1.973	2.299
-240		1.033	1.074	1.126	1.189	1.267	1.362	1.478	1.624	1.806	2.041

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TABLE VIII.

THERMAL CONDUCTIVITY OF NITROGEN

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
Saturated vapor line	-300	.00556	Thodos correlations
	-250	.00955	Thodos correlations
	-240	.01176	Thodos correlations
	-232.6	.02099	Thodos correlations
1 atmosphere*	-279.7	.00539	NBS Compendium (3.004)
	-208	.00753	NBS Circular 564
	-189.7	.00796	NBS Compendium (3.004)
	-99.7	.01057	NBS Compendium (3.004)
	-64	.01152	NBS Circular 564
	-9.7	.01277	NBS Compendium (3.004)
	+80.3	.01490	NBS Compendium (3.004)
	+106.0	.01565	NBS Compendium (3.004)
	+200	.01790	TDB 106.141
	+300	.02010	TDB 106.141
	+400	.0222	TDB 106.141
	+440	.0230	NBS Circular 564
500 PSIA	-297.7	.0709	NBS Compendium (3.004)
	-279.7	.0608	NBS Compendium (3.004)
	-243.7	.0405	NBS Compendium (3.004)
	-225.7 -	.0262	- linear interpolation
	-215.0	.0122	TDB 106.141
	-207.7	.0119	NBS Compendium (3.004)
	-171.7	.0118	NBS Compendium (3.004)
	-135.7	.0120	NBS Compendium (3.004)
	0	.01427	Thodos correlations
	+100	.0164	Thodos correlations
	+127	.0171	Lenoir, Junk, and Comings
	+250	.0198	TDB 106.141

*primary weight given to Compendium points.

TABLE VIII.

THERMAL CONDUCTIVITY OF NITROGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
500 PSIA (continued)	+350	.02185	TDB 106.141
	+450	.0238	TDB 106.141
1000 PSIA	-297.7	.0734	NBS Compendium (3.004)
	-243.7	.0458	NBS Compendium (3.004)
	-207.7	.0276	NBS Compendium (3.004)
	-171.7	.0172	NBS Compendium (3.004)
	-135.7	.0148	NBS Compendium (3.004)
	-99.7	.0145	NBS Compendium (3.004)
	0	.01596	Thodos correlations
	+100	.0176	Thodos correlations
	+250	.02045	TDB 106.141
	+350	.02235	TDB 106.141
	+450	.0243	TDB 106.141
1500 PSIA	-297.7	.0751	NBS Compendium (3.004)
	-243.7	.0503	NBS Compendium (3.004)
	-207.7	.0356	NBS Compendium (3.004)
	-135.7	.0199	NBS Compendium (3.004)
	-99.7	.0181	NBS Compendium (3.004)
	0	.0178	Thodos correlations
	+100	.0189	Thodos correlations
	+200	.0203	TDB 106.141
	+350	.0230	TDB 106.141
	+450	.02485	TDB 106.141
2000 PSIA	-300	.0777	Thodos correlations
	-279.7	.0694	NBS Compendium (3.004)
	-243.7	.0534	NBS Compendium (3.004)
	-171.7	.0304	NBS Compendium (3.004)
	-135.7	.0246	NBS Compendium (3.004)

TABLE VIII.

THERMAL CONDUCTIVITY OF NITROGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
2000 PSIA (continued)	-99.7	.0213	NBS Compendium (3.004)
	0	.02016	Thodos correlations
	+100	.0206	Thodos correlations
	+200	.0216	Thodos correlations
	+300	.0228	Thodos correlations
	+400	.0244	TDB 106.141
2500 PSIA	-300	.0819	Thodos correlations
	-250	.0632	Thodos correlations
	-200	.0426	Thodos correlations
	-150	.0346	Thodos correlations
	-100	.0273	Thodos correlations
	-75	.0246	Thodos correlations
	-50	.0233	Thodos correlations
	0	.02226	Thodos correlations
	+100	.02215	Thodos correlations
	+200	.0227	Thodos correlations
	+300	.0239	Thodos correlations
	+400	.0250	Thodos correlations
	+500	.0268	Thodos correlations
3000 PSIA	-300	.0824	Thodos correlations
	-250	.0672	Thodos correlations
	-200	.0514	Thodos correlations
	-100	.0304	Thodos correlations
	-50	.0265	Thodos correlations
	0	.0244	Thodos correlations
	+100	.0232	Thodos correlations
	+200	.0239	Thodos correlations
	+300	.0247	Thodos correlations
	+400	.0256	Thodos correlations

TABLE VIII

THERMAL CONDUCTIVITY OF NITROGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
3500 PSIA	-300	.0848	Thodos correlations
	-250	.0693	Thodos correlations
	-200	.0556	Thodos correlations
	-100	.0338	Thodos correlations
	0	.0269	Thodos correlations
	+100	.0250	Thodos correlations
	+200	.0251	Thodos correlations
	+300	.0257	Thodos correlations
	+400	.0264	Thodos correlations
	+500	.0273	Thodos correlations
		(Additional Points)	
1500 PSIA	+122	.0193	Nuttall and Ginnings
(100 atmospheres)	+212	.0203	Nuttall and Ginnings
1000 PSIA	+122	.0181	Nuttall and Ginnings
(68 atmospheres-interpolated)	+212	.0195	Nuttall and Ginnings

TABLE IX.

THERMAL CONDUCTIVITY OF OXYGEN

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
Saturated Vapor	-320	.00446	Thodos correlation
	-300	.00510	Thodos correlation
	-270	.00675	Thodos correlation
	-250	.00790	Thodos correlation
	-230	.00892	Thodos correlation
	-225	.00930	Thodos correlation
	-220	.00993	Thodos correlation
	-210	.0109	Thodos correlation
	-200	.0121	Thodos correlation
	-190	.0148	Thodos correlation
	-185	.0188	Thodos correlation
	-191.10	.02547	Thodos correlation
1 atmosphere	-296.8	.00454	Ziebland and Burton
	-292	.0048	Tsederberg and Timrot
	-279.7	.0050	NBS Compendium
	-261.7	.00544	Ziebland and Burton
	-256	.0059	Tsederberg and Timrot
	-243.7	.00605	Ziebland and Burton
	-220	.0070	Tsederberg and Timrot
	-207.7	.00726	Ziebland and Burton
	-189.7	.0075	NBS Compendium
	-184	.0081	Tsederberg and Timrot
	-171.7	.00847	Ziebland and Burton
	-148	.0091	Tsederberg and Timrot
	-135.7	.00907	Ziebland and Burton
	-117.7	.00968	Ziebland and Burton
	-112	.0102	Tsederberg and Timrot
	-99.7	.01028	Ziebland and Burton
	-99.7	.0100	NBS Compendium

TABLE IX.

THERMAL CONDUCTIVITY OF OXYGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
1 atmosphere (continued)	-76	.0112	Tsederberg and Timrot
	-40	.0122	Tsederberg and Timrot
	-10	.01305	NBS Circular 564
	-9.7	.0125	NBS Compendium
	-4	.0132	Tsederberg and Timrot
	+32	.0141	Tsederberg and Timrot
	+68	.0151	Tsederberg and Timrot
	+104	.0160	Tsederberg and Timrot
	+152	.01731	NBS Circular 564
	+206	.01873	NBS Circular 564
	+260	.02001	NBS Circular 564
	+314	.02128	NBS Circular 564
	+404	.02327	NBS Circular 564
	+494	.02526	NBS Circular 564
500 PSIA	-195	.0125	Thodos correlation
	-189.7	.0124	Ziebland and Burton
	-184	.0119	Tsederberg and Timrot
	-148	.0114	Tsederberg and Timrot
	-112	.0120	Tsederberg and Timrot
	-99.7	.0127	Ziebland and Burton
	-76	.0127	Tsederberg and Burton
	-40	.0136	Tsederberg and Burton
	-4	.0143	Tsederberg and Burton
	+32	.0151	Tsederberg and Burton
	+68	.0160	Tsederberg and Burton
	+104	.0169	Tsederberg and Burton
	+150	.0178	Thodos correlation
	+200	.0193	TDB 106.144
	+250	.0205	TDB 106.144
	+350	.02275	TDB 106.144
	+450	.0250	TDB 106.144

TABLE IX.

THERMAL CONDUCTIVITY OF OXYGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
1000 PSIA	-170	.0280	Thodos correlation
	-165	.0267	Thodos correlation
	-160	.0204	Thodos correlation
	-153.7	.02026	Ziebland and Burton
	-148	.0176	Tsederberg and Timrot
	-135.7	.01663	Ziebland and Burton
	-117.7	.01512	Ziebland and Burton
	-112	.0152	Tsederberg and Timrot
	-99.7	.01482	Ziebland and Burton
	-76	.0151	Tsederberg and Timrot
	-40	.0154	Tsederberg and Timrot
	-4	.0159	Tsederberg and Timrot
	+32	.0165	Tsederberg and Timrot
	+68	.0173	Tsederberg and Timrot
	+104	.0181	Tsederberg and Timrot
	+200	.0203	TDB 106.144
	+250	.02145	TDB 106.144
	+350	.02355	TDB 106.144
	+450	.0237	TDB 106.144
1500 PSIA	-148	.0273	Tsederberg and Timrot
	-135.7	.0248	Ziebland and Burton
	-117.7	.02117	Ziebland and Burton
	-112	.0206	Tsederberg and Timrot
	-99.7	.01996	Ziebland and Burton
	-76	.0185	Tsederberg and Timrot
	-40	.0178	Tsederberg and Timrot
	-4	.0180	Tsederberg and Timrot
	+32	.0182	Tsederberg and Timrot
	+68	.0188	Tsederberg and Timrot

TABLE IX.

THERMAL CONDUCTIVITY OF OXYGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
1500 PSIA (continued)	+104	.0195	Tsederberg and Timrot
	+250	.02165	Thodos correlation
	+300	.02295	TDB 106.144
	+400	.0250	TDB 106.144
2000 PSIA	-117.7	.0275	Ziebland and Burton
	-99.7	.0254	Ziebland and Burton
	-80	.0239	Thodos correlation
	-50	.0219	Thodos correlation
	-20	.0209	Thodos correlation
	+10	.0206	Thodos correlation
	+70	.0209	Thodos correlation
	+150	.0214	Thodos correlation
	+250	.0227	Thodos correlation
	+350	.0247	TDB 106.144
	+450	.0266	TDB 106.144
2500 PSIA	-50	.0255	Thodos correlation
	+10	.0232	Thodos correlation
	+70	.0224	Thodos correlation
	+150	.0227	Thodos correlation
	+250	.0237	Thodos correlation
	+350	.0247	TDB 106.144
	+450	.0270	TDB 106.144
3000 PSIA	-20	.0273	Thodos correlation
	+10	.0260	Thodos correlation
	+70	.0247	Thodos correlation
	+150	.0246	Thodos correlation
	+250	.0252	Thodos correlation
	+300	.0255	TDB 106.144
	+350	.0261	TDB 106.144
	+400	.02675	TDB 106.144

TABLE IX.

THERMAL CONDUCTIVITY OF OXYGEN (continued)

Pressure	Temperature °F	Thermal Conductivity (K) Btu/hr-ft-°F	Source
3500 PSIA	+30	.0273	Thodos correlation
	+100	.0261	Thodos correlation
	+150	.0260	Thodos correlation
	+200	.0262	Thodos correlation
	+250	.0257	TDB 106.144
	+300	.0262	TDB 106.144
	+400	.0274	TDB 106.144
4000 PSIA	+70	.0285	Thodos correlation
	+150	.0273	Thodos correlation
	+250	.0274	Thodos correlation
	+350	.0280	Thodos correlation
	+400	.0285	Thodos correlation

TABLE X.

THERMAL CONDUCTIVITY OF SATURATED LIQUID NITROGEN

Temperature (°F)	K (Btu/hr-ft-°R)	Source of Data
-346.1	0.0966	Thodos correlation
-346	0.0895	Riedel correlation
-336.1	0.0881	Powers, et al.
-333.8	0.9854	Powers, et al.
-328	0.0937	Borovik, et al.
-327.1	0.0832	Powers, et al.
-324	0.0794	Riedel correlation
-322.4	0.0820	Powers, et al.
-320	0.0819	Thodos correlation
-319.9	0.0806	Powers, et al.
-319.1	0.0774	Uhlir
-319	0.0877	Borovik, et al.
-313.7	0.0769	Powers, et al.
-310	0.0816	Borovik, et al.
-308.9	0.0755	Powers, et al.
-304.1	0.0743	Powers, et al.
-301.1	0.0726	Powers, et al.
-301	0.0756	Borovik, et al.
-301	0.0685	Riedel correlation
-300	0.0724	Thodos correlation
-292	0.0695	Borovik, et al.
-283	0.0635	Borovik, et al.
-280	0.0603	Thodos correlation
-279.7	0.0568	Uhlir
-278	0.0562	Riedel correlation
-274	0.0575	Borovik, et al.
-270	0.0556	Thodos correlation
-265	0.0514	Borovik, et al.
-260	0.0483	Thodos correlation
-256	0.0454	Borovik, et al.

TABLE X.

THERMAL CONDUCTIVITY OF SATURATED LIQUID NITROGEN (continued)

Temperature (°F)	K (Btu/hr-ft-°R)	Source of Data
-256	0.0418	Riedel correlation
-250	0.0430	Thodos correlation
-245	0.0388	Thodos correlation
-244.6	0.0387	Uhlir
-240	0.0340	Thodos correlation
-235	0.0298	Thodos correlation
-232.6	0.0210	Thodos correlation

Borovik, et al.

Temperature (°C)	Temperature (°F)	K (Cal/cm-sec-°K)	K (Btu/hr-ft-°K)
-200	-328	3.875×10^{-4}	.0937
-195	-319	3.625	.0877
-190	-310	3.375	.0816
-185	-301	3.125	.0756
-180	-292	2.875	.0695
-175	-283	2.625	.0635
-170	-274	2.375	.0575
-165	-265	2.125	.0514
-160	-256	1.875	.0454

TABLE X.

THERMAL CONDUCTIVITY OF SATURATED LIQUID NITROGEN (continued)

Powers, Mattox, and Johnston (NBS Compendium)

Temperature (°K)	Temperature (°F)	K (Cal/cm-sec-°K)	K (Btu/cm-sec-°R)
68.68	-336.07	3.64	.0881
69.92	-333.83	3.53	.0854
73.66	-327.10	3.44	.0832
76.26	-322.42	3.39	.0820
77.66	-319.90	3.33	.0806
78.73	-317.98	3.31	.0801 (omitted)
81.11	-313.69	3.18	.0769
81.77	-312.50	3.15	.0762
83.77	-308.90	3.12	.0755
86.44	-304.10	3.07	.0743
88.12	-301.07	3.00	.0726

Uhlir

Temperature (°F)	K (Btu/hr-ft-°R)
-319.1	.0774
-279.7	.0568
-244.6	.0387

TABLE XI.

THERMAL CONDUCTIVITY OF SATURATED LIQUID OXYGEN

Temperature °F	K (Btu/hr-ft-°R)	Source of Data
-360	.1086	Tsederberg and Timrot
-350	.1051	Tsederberg and Timrot
-343.3	.1036	Tsederberg and Timrot
-324.7	.0950	From Compendium
-320.4	.1170	Thodos correlation
-315.7	.0943	Tsederberg and Timrot
-306.7	.1095	Thodos correlation
-297.7	.0840	From Compendium
-288.7	.0834	Tsederberg and Timrot
-288.7	.0994	Thodos correlation
-279.7	.0786	Ziebland and Burton
-270.7	.0750	Ziebland and Burton
-270.7	.0685	From Compendium
-261.7	.0718	Tsederberg and Timrot
-252.7	.0671	Ziebland and Burton
-243.7	.0636	Tsederberg and Timrot
-243.7	.0625	From Compendium
-243.7	.0587	Ziebland and Burton
-225.7	.0559	Tsederberg and Timrot
-207.7	.0469	Tsederberg and Timrot
-198.7	.0411	Ziebland and Burton
-189.7	.0346	Tsederberg and Timrot
-185.2	.0317	Tsederberg and Timrot
-185.2	.0314	Ziebland and Burton
-181.1	.0236	Tsederberg and Timrot
-181.1	.0242	Ziebland and Burton

TABLE XII.

DENSITY OF OXYGEN, SUPERHEATED VAPOR

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
10	-279.7	0.168	NBS Circular 564
	-256	0.148	Leiden Chart
	-202	0.117	Leiden Chart
	-171.7	0.104	NBS Circular 564
	-112	0.0860	Leiden Chart
	-45.7	0.0722	NBS Circular 564
	+32	0.0604	Leiden Chart
	+80.3	0.0553	NBS Circular 564
14.7	-279.7	0.249	NBS Circular 564
	-238	0.197	Leiden Chart
	-171.7	0.153	NBS Circular 564
	-112	0.124	Leiden Chart
	-45.7	0.106	NBS Circular 564
	+32	0.0884	Leiden Chart
	+80.3	0.0812	NBS Circular 564
20	-274	0.330	Leiden Chart
	-207.7	0.241	NBS Circular 564
	-135.7	0.186	NBS Circular 564
	-112	0.171	Leiden Chart
	-45.7	0.145	NBS Circular 564
	+32	0.120	Leiden Chart
	+80.3	0.111	NBS Circular 564
30	-256	0.450	Leiden Chart
	-207.7	0.365	NBS Circular 564
	-184	0.323	Leiden Chart
	-135.7	0.280	NBS Circular 564
	-45.7	0.217	NBS Circular 564
	+32	0.182	Leiden Chart
	+80.3	0.166	NBS Circular 564

TABLE XII.

DENSITY OF OXYGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (° F)	Density (#/ft^3)	Source of Data
40	-256	0.608	Leiden Chart
	-153.7	0.397	NBS Circular 564
	-112	0.342	Leiden Chart
	-63.7	0.303	NBS Circular 564
	-4	0.264	Leiden Chart
	+62.3	0.229	NBS Circular 564
60	-225.7	0.802	NBS Circular 564
	-184	0.666	Leiden Chart
	-153.7	0.597	NBS Circular 564
	-112	0.514	Leiden Chart
	-63.7	0.456	NBS Circular 564
	-4	0.397	Leiden Chart
	+62.3	0.344	NBS Circular 564
	+104	0.315	Leiden Chart
80	-256	1.28	Leiden Chart
	-225.7	1.09	NBS Circular 564
	-184	0.899	Leiden Chart
	-153.7	0.803	NBS Circular 564
	-112	0.696	Leiden Chart
	-63.7	0.610	NBS Circular 564
	+32	0.488	Leiden Chart
	+62.3	0.459	NBS Circular 564
100	-220	1.32	Leiden Chart
	-171.7	1.08	NBS Circular 564
	-130	0.920	Leiden Chart
	-81.7	0.803	NBS Circular 564
	-40	0.716	Leiden Chart
	+8.3	0.642	NBS Circular 564
	+68	0.565	Leiden Chart
	+116.3	0.519	NBS Circular 564

TABLE XII.

DENSITY OF OXYGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
150	-220	2.07	Leiden Chart
	-171.7	1.62	NBS Circular 564
	-130	1.42	Leiden Chart
	-81.7	1.19	NBS Circular 564
	-40	1.08	Leiden Chart
	+8.3	0.947	NBS Circular 564
	+68	0.854	Leiden Chart
200	-220	2.89	Leiden Chart
	-130	1.92	Leiden Chart
	-81.7	1.67	NBS Circular 564
	-40	1.47	Leiden Chart
	+8.3	1.30	NBS Circular 564
	+68	1.14	Leiden Chart
	+116.3	1.04	NBS Circular 564
300	-202	4.34	Leiden Chart
	-130	2.99	Leiden Chart
	-81.7	2.58	NBS Circular 564
	-40	2.22	Leiden Chart
	+68	1.73	Leiden Chart
	+116.3	1.57	NBS Circular 564
400	-202	6.46	Leiden Chart
	-130	4.10	Leiden Chart
	-81.7	3.48	NBS Circular 564
	-40	3.00	Leiden Chart
	+8.3	2.66	NBS Circular 564
	+68	2.32	Leiden Chart
	+116.3	2.10	NBS Circular 564

TABLE XII.

DENSITY OF OXYGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
600	-184	10.7	Leiden Chart
	-148	7.35	Leiden Chart
	-112	6.01	Leiden Chart
	-45.7	4.66	NBS Circular 564
	+32	3.73	Leiden Chart
	+62.3	3.51	NBS Circular 564
	+116.3	3.15	NBS Circular 564
800	-166	14.3	Leiden Chart
	-130	9.64	Leiden Chart
	-76	7.16	Leiden Chart
	-45.7	6.45	NBS Circular 564
	+8.3	5.44	NBS Circular 564
	+68	4.67	Leiden Chart
	+116.3	4.23	NBS Circular 564
1000	-148	16.4	Leiden Chart
	-76	9.32	Leiden Chart
	-45.7	8.31	NBS Circular 564
	+8.3	6.94	NBS Circular 564
	+68	5.84	Leiden Chart
	+116.3	5.36	NBS Circular 564
1500	-148	32.7	Leiden Chart
	-76	15.0	Leiden Chart
	-45.7	12.93	NBS Circular 564
	+8.3	10.56	NBS Circular 564
	+68	8.92	Leiden Chart
	+116.3	7.99	NBS Circular 564

TABLE XII.

DENSITY OF OXYGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
2000	-148	40.5	Leiden Chart
	-76	21.4	Leiden Chart
	-4	15.0	Leiden Chart
	+68	12.0	Leiden Chart
2500	-148	44.7	Leiden Chart
	-76	27.1	Leiden Chart
	-4	18.9	Leiden Chart
	+68	15.0	Leiden Chart
3000	-148	47.7	Leiden Chart
	-76	31.7	Leiden Chart
	-4	22.7	Leiden Chart
	+68	17.8	Leiden Chart
3500	-130	46.3	Leiden Chart
	-76	35.4	Leiden Chart
	-4	25.8	Leiden Chart
	+68	20.7	Leiden Chart
4000	-112	44.7	Leiden Chart
	-40	33.0	Leiden Chart
	+32	25.7	Leiden Chart
	+104	21.3	Leiden Chart

TABLE XIII.

DENSITY OF OXYGEN, SATURATED LIQUID

Temperature, °F	Density (#/ft^3)	Source of Data
-349.9	80.04	Van Itterbeek
-346.8	79.57	Mathias and Onnes
-343.3	78.54	Van Itterbeek and Verbeke
-342.7	78.85	Van Itterbeek
-333.7	77.35	Van Itterbeek
-325.1	75.60	Van Itterbeek and Verbeke
-324.7	75.85	Van Itterbeek
-315.7	74.35	Van Itterbeek
-315.4	74.12	Van Itterbeek and Verbeke
-306.7	72.86	Van Itterbeek
-306.0	72.64	Van Itterbeek and Verbeke
-297.7	71.30	Van Itterbeek
-295.7	71.26	Mathias and Onnes
-292.5	71.1	Byrne and Thodos
-297.7	68.20	Van Itterbeek and Verbeke
-264.7	65.8	Byrne and Thodos
-256	63.65	Van Itterbeek and Verbeke*
-246.2	60.92	Mathias and Onnes
-240	60.13	Van Itterbeek and Verbeke*
-230	57.65	Van Itterbeek and Verbeke
-220.5	54.58	Mathias and Onnes
-217.3	53.7	Byrne and Thodos
-210	51.67	Van Itterbeek and Verbeke*
-201.9	48.58	Mathias and Onnes
-195	44.86	Van Itterbeek and Verbeke*
-190	42.32	Mathias and Onnes
-188.1	40.3	Byrne and Thodos
-184.8	37.66	Mathias and Onnes
-181.1	26.84	Byrne and Thodos

* calculated

TABLE XIV

DENSITY OF OXYGEN, SATURATED VAPOR

Temperature, °F	Density (#/ft^3)	Source of Data
-328.7	0.0325	Extrapolated
-320	0.062	Extrapolated
-310	0.125	Extrapolated
-303.5	0.182	Leiden Chart
-300	0.235	Extrapolated
-297.3	0.271	Leiden Chart
-292	0.377	Leiden Chart
-284	0.545	Leiden Chart
-274	0.840	Leiden Chart
-261.5	1.43	Leiden Chart
-256	1.68	Leiden Chart
-243	2.65	Leiden Chart
-238	3.03	Leiden Chart
-220	5.07	Leiden Chart
-209	6.71	Byrne and Thodos
-202	8.35	Leiden Chart
-195	10.74	Byrne and Thodos
-184	18.7	Leiden Chart
-181.1	26.84	Byrne and Thodos

TABLE XV

DENSITY OF NITROGEN, SUPERHEATED VAPOR

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
10	-300	0.167	Leiden Chart
	-261.7	0.133	NBS Circular 564
	-225.7	0.112	NBS Circular 564
	-180	0.0936	Leiden Chart
	-90	0.0707	Leiden Chart
	0	0.0568	Leiden Chart
	+44.3	0.0518	NBS Circular 564
	+116.3	0.0454	NBS Circular 564
15	-300	0.253	Leiden Chart
	-261.7	0.201	NBS Circular 564
	-225	0.169	NBS Circular 564
	-180	0.141	Leiden Chart
	-90	0.103	Leiden Chart
	0	0.0853	Leiden Chart
	+44.3	0.0763	NBS Circular 564
	+116.3	0.0680	NBS Circular 564
20	-300	0.341	Leiden Chart
	-261.7	0.272	NBS Circular 564
	-225.7	0.227	NBS Circular 564
	-180	0.188	Leiden Chart
	-90	0.142	Leiden Chart
	0	0.114	Leiden Chart
	+44.3	0.104	NBS Circular 564
	+116.3	0.0906	NBS Circular 564
25	-300	0.432	Leiden Chart
	-261.7	0.343	NBS Circular 564
	-225.7	0.285	NBS Circular 564
	-180	0.236	Leiden Chart

TABLE XV

DENSITY OF NITROGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (lb/ft^3)	Source of Data
25 (cont'd)	-90	0.178	Leiden Chart
	0	0.142	Leiden Chart
	+44.3	0.129	NBS Circular 564
	+116.3	0.113	NBS Circular 564
30	-300	0.526	Leiden Chart
	-261.7	0.414	NBS Circular 564
	-225.7	0.344	NBS Circular 564
	-180	0.283	Leiden Chart
	-90	0.213	Leiden Chart
	0	0.170	Leiden Chart
	+44.3	0.155	NBS Circular 564
	+116.3	0.136	NBS Circular 564
40	-300	0.716	Leiden Chart
	-261.7	0.557	NBS Circular 564
	-225.7	0.460	NBS Circular 564
	-180	0.378	Leiden Chart
	-90	0.284	Leiden Chart
	0	0.228	Leiden Chart
	+44.3	0.207	NBS Circular 564
	+116.3	0.181	NBS Circular 564
50	-250	0.652	Leiden Chart
	-180	0.475	Leiden Chart
	-90	0.355	Leiden Chart
	-45.7	0.317	NBS Circular 564
	0	0.280	Leiden Chart
	+44.3	0.253	NBS Circular 564
	+116.3	0.226	NBS Circular 564

TABLE XV

DENSITY OF NITROGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
60	-250	0.789	Leiden Chart
	-180	0.571	Leiden Chart
	-90	0.427	Leiden Chart
	-45.7	0.380	NBS Circular 564
	0	0.342	Leiden Chart
	+44.3	0.311	NBS Circular 564
	+116.3	0.272	NBS Circular 564
80	-250	1.07	Leiden Chart
	-180	0.767	Leiden Chart
	-90	0.570	Leiden Chart
	-45.7	0.508	NBS Circular 564
	0	0.456	Leiden Chart
	+44.3	0.415	NBS Circular 564
	+116.3	0.363	NBS Circular 564
100	-250	1.37	Leiden Chart
	-180	0.966	Leiden Chart
	-90	0.715	Leiden Chart
	-45.7	0.636	NBS Circular 564
	0	0.571	Leiden Chart
	+44.3	0.519	NBS Circular 564
	+116.3	0.453	NBS Circular 564
150	-250	2.18	Leiden Chart
	-180	1.48	Leiden Chart
	-90	1.08	Leiden Chart
	-45.7	0.956	NBS Circular 564
	0	0.858	Leiden Chart
	+44.3	0.778	NBS Circular 564
	+116.3	0.679	NBS Circular 564

TABLE XV

DENSITY OF NITROGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
200	-250	3.12	Leiden Chart
	-180	2.01	Leiden Chart
	-135.7	1.73	NBS Circular 564
	-90	1.45	Leiden Chart
	0	1.15	Leiden Chart
	+44.3	1.04	NBS Circular 564
	+116.3	0.905	NBS Circular 564
250	-250	4.26	Leiden Chart
	-180	2.56	Leiden Chart
	-90	1.82	Leiden Chart
	-45.7	1.62	NBS Circular 564
	0	1.43	Leiden Chart
	+44.3	1.30	NBS Circular 564
	+116.3	1.13	NBS Circular 564
300	-250	5.90	Leiden Chart
	-180	3.14	Leiden Chart
	-90	2.20	Leiden Chart
	-45.7	1.96	NBS Circular 564
	0	1.73	Leiden Chart
	+44.3	1.57	NBS Circular 564
	+116.3	1.36	NBS Circular 564
400	-230	7.01	Leiden Chart
	-180	4.38	Leiden Chart
	-90	2.80	Leiden Chart
	-45.7	2.62	NBS Circular 564
	0	2.31	Leiden Chart
	+44.3	2.09	NBS Circular 564
	+116.3	1.81	NBS Circular 564

TABLE XV

DENSITY OF NITROGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
500	-230	12.2	Leiden Chart
	-180	5.78	Leiden Chart
	-90	3.77	Leiden Chart
	-45.7	3.29	NBS Circular 564
	0	2.90	Leiden Chart
	+44.3	2.62	NBS Circular 564
	+116.3	2.26	NBS Circular 564
600	-230	28.1	Leiden Chart
	-180	7.31	Leiden Chart
	-90	4.58	Leiden Chart
	-45.7	3.95	NBS Circular 564
	0	3.49	Leiden Chart
	+44.3	3.14	NBS Circular 564
	+116.3	2.71	NBS Circular 564
800	-230	31.9	Leiden Chart
	-180	10.9	Leiden Chart
	-90	6.23	Leiden Chart
	-45.7	5.34	NBS Circular 564
	0	4.67	Leiden Chart
	+44.3	4.19	NBS Circular 564
	+116.3	3.61	NBS Circular 564
1000	-230	34.1	Leiden Chart
	-180	15.2	Leiden Chart
	-90	7.94	Leiden Chart
	-45.7	6.73	NBS Circular 564
	0	5.86	Leiden Chart
	+44.3	5.24	NBS Circular 564
	+116.3	4.50	NBS Circular 564

TABLE XV

DENSITY OF NITROGEN, SUPERHEATED VAPOR (continued)

Pressure (PSIA)	Temperature (°F)	Density (#/ft^3)	Source of Data
1500	-230	27.9	Leiden Chart
	-200	28.5	Benedict
	-180	23.9	Leiden Chart
	-150	17.9	Benedict
	-90	17.9	Leiden Chart
	-45.7	10.2	NBS Circular 564
	0	8.84	Leiden Chart
	+44.3	7.84	NBS Circular 564
	+116.3	6.69	NBS Circular 564

TABLE XVI.

DENSITY OF NITROGEN, SATURATED LIQUID

Temperature, °F	Density (#/ft^3)	Source of Data
-343.2	53.83	NBS Compendium, 1.004
-337.8	53.06	Mathias, et al.
-328.1	50.60	Mathias, et al.
-323.4	50.83	Byrne and Thodos
-319.3	50.21	NBS Compendium, 1.004
-310	48.72	Byrne and Thodos
-300.7	47.09	Byrne and Thodos
-296.5	46.40	Mathias, et. al.
-290	45.15	Leiden Chart
-280.7	43.21	Mathias, et al.
-277.9	42.68	Byrne and Thodos
-270	40.92	Leiden Chart
-258.2	37.90	Mathias, et al.
-255.3	36.92	Byrne and Thodos
-250	35.46	Leiden Chart
-244.6	33.29	Mathias, et al.
-243.9	33.00	Byrne and Thodos
-240	30.88	Leiden Chart
-237.6	29.96	Mathias, et al.
-234.7	26.93	NBS Compendium, 1.004
-232.6	19.41	Byrne and Thodos

TABLE XVII.

DENSITY OF NITROGEN, SATURATED VAPOR

Temperature, °F	Density (#/ft^3)	Source of Data
-343.2	0.0542	NBS Compendium, 1.004
-326	0.2020	Leiden Chart
-323.4	0.252	Byrne and Thodos
-320	0.2939	Leiden Chart
-319.3	0.3109	NBS Compendium, 1.004
-315.5	0.3840	Leiden Chart
-311.8	0.4737	Leiden Chart
-308.5	0.5612	Leiden Chart
-303	0.7358	Leiden Chart
-300.7	0.837	Byrne and Thodos
-298.5	0.9074	Leiden Chart
-296.7	0.9839	NBS Compendium, 1.004
-294.6	1.0800	Leiden Chart
-288.1	1.427	Leiden Chart
-282.8	1.777	Leiden Chart
-280.9	1.849	NBS Compendium, 1.004
-277.9	1.999	Byrne and Thodos
-272	2.682	Leiden Chart
-263.7	3.655	Leiden Chart
-258.3	4.362	NBS Compendium, 1.004
-256.7	4.737	Leiden Chart
-255.3	4.775	Byrne and Thodos
-250.7	5.963	Leiden Chart
-244.7	7.348	NBS Compendium, 1.004
-243.9	7.415	Byrne and Thodos
-240.5	9.058	Leiden Chart
-234.7	12.49	NBS Compendium, 1.004
-232.6	19.41	Byrne and Thodos

TABLE XVIII.

PRANDTL NUMBER OF NITROGEN

Temperature (°F)	Cp (Btu/# °F)	μ (#/ft-hr)	K (Btu/hr-ft-°F)	N Pr
Saturated Liquid				
-333.7	0.484	0.530	0.0862	2.98
-324.7	0.487	0.425	0.0824	2.51
-315.7	0.492	0.345	0.0785	2.16
-306.7	0.499	0.292	0.0745	1.96
-297.7	0.507	0.255	0.0703	1.84
-288.7	0.518	0.223	0.0658	1.76
-279.7	0.535	0.196	0.0610	1.72
-270.7	0.561	0.176	0.0558	1.77
-261.7	0.650	0.148	0.0502	1.78
-250.9	0.659	0.128	0.0435	1.94

NOTES:

Cp taken from Compendium Graph 4.004.
K taken from revised N_2 thermal conductivity graph.
μ taken from revised N_2 viscosity graph.

Saturated Vapor				
-272	0.339	0.0198	0.00720	.932
-256.7	0.393	0.0237	0.00880	1.06
-250.5	0.448	0.0260	0.00980	1.19
-240.5	0.478	0.0313	0.0128	1.17

NOTES:

Cp values determined by extrapolation of values in Folder 105.141 (rev. 1) to the saturation temperature at a given pressure.
μ and K values taken from revised graphs.

TABLE XVIII.

PRANDTL NUMBER OF NITROGEN (continued)

Temperature (°F)	Cp (Btu/# °F)	μ (#/ft-hr)	K(Btu/hr-ft-°F)	N_{Pr}
14.7 PSIA				
-279.7	0.256[A]	0.0166	0.0054	.787
+32	0.2488[B]	0.0402	0.01377	.726
+116.3	0.2487[A]	0.0452	0.01590	.707
+206.3	0.249[A]	0.0503	0.01800	.696
+296.3	0.250[A]	0.0552	0.02005	.688

NOTES:

A Taken from NBS Circular 564.
B Taken from NBS Compendium, 4.004.
μ and K taken from revised graphs.

(Additional NBS Circular 564 (p. 359) data.)

-243.7	.....	0.778	.....	.....
-207.7	.....	0.770	.....	.....
-171.7	.....	0.762	.....	.....
-135.7	.....	0.754	.....	.....
-99.7	.....	0.747	.....	.....
-63.7	.....	0.740	.....	.....
+8.3	.....	0.725	.....	.....
+80.3	.....	0.713	.....	.....
200 PSIA				
-171.7	0.279[A]	0.0280	0.0100[C]	.781
-135.7	0.269[B]	0.0303	0.0108[C]	.755
+100	0.253[B]	0.0448	0.0159[D]	.713
+200	0.252[B]	0.0504	0.0183[D]	.694
+300	0.252[B]	0.0559	0.0204[D]	.691

TABLE XVIII.

PRANDTL NUMBER OF NITROGEN (continued)

Temperature (°F)	Cp (Btu/# °F)	μ (#/ft-hr)	K (Btu/hr-ft-°F)	N Pr
200 PSIA (continued)				

NOTES:

A Source - Folder 105.141 (Rev. 1).
B Source - NBS Circular 564.
C Values taken from crossplot of NBS Compendium 3.004.
D Values interpolated from revised graph.
Also, values of μ interpolated from revised graph.

300 PSIA				
-207.7	0.324 A	0.0267	0.0099 B	.874
-171.7	0.295 A	0.0285	0.0105 B	.798
-135.7	0.284	0.0307	0.0112 B	.778
-99.7	0.272	0.0333	0.0123 B	.736
0	0.259	0.0394	0.0137	.745
+100	0.260	0.0450	0.01605	.728
+200	0.254	0.0506	0.01835	.700
+300	0.253	0.0651	0.0205	.692

NOTES:

These N_{Pr} values not plotted on graph.
A Taken from Folder 105.141 (Rev. 1); remainder of Cp values from NBS Circular 564.
B Values taken from crossplot of NBS Compendium 3.004.
Remaining values of K and μ interpolated from revised graphs.

TABLE XVIII.

PRANDTL NUMBER OF NITROGEN (continued)

Temperature (°F)	Cp (Btu/# °F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	Npr
500 PSIA				
-215	0.460[A]	0.0290	0.01210	1.102
-210	0.438[A]	0.0288	0.01193	1.057
-200	0.401[B]	0.0290	0.0118	.985
-160	0.325[B]	0.0305	0.0118	.840
-120	0.297[B]	0.0332	0.0122	.808
-80	0.283[B]	0.0356	0.0128	.787
-40	0.274[B]	0.0378	0.01355	.764
0	0.268[B]	0.0399	0.0143	.748
+116.3	0.259	0.0465	0.0168	.717
+206.3	0.257	0.0515	0.0188	.704

NOTES:

A Extrapolated values from Cp - T curve.
B Taken from Folder 105.141 (Rev. 1); remaining values from NBS Circular 564.
Values of μ and K read from revised graphs.

1000 PSIA				
-148	0.423[A]	0.0397	0.0153	1.097
-117.7	0.364	0.0393	0.01455	.983
-80	0.328	0.0397	0.0146	.892
-60	0.314	0.0402	0.0149	.865
-40	0.304	0.0410	0.0152	.820
0	0.290	0.0424	0.0159	.773
+44.3	0.279	0.0445	0.01665	.746
+116.3	0.270	0.0482	0.01795	.725
+206.3	0.264	0.0528	0.0196	.711

TABLE XVIII

PRANDTL NUMBER OF NITROGEN (continued)

Temperature (°F)	Cp (Btu/# °F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	N_{Pr}
1000 PSIA (continued)				
NOTES:				
A Source - NBS Compendium, 4.004; remaining values from NBS Circular 564.				
K and μ values from revised graphs.				
1500 PSIA				
-193	0.630 A	0.0720	0.031	1.46
-148	0.526 A	0.0445	0.0214	1.094
-103	0.397 A	0.0427	0.0182	.931
-63.7	0.347	0.0426	0.0177	.835
-27.7	0.320	0.0433	0.01765	.785
+26.3	0.298	0.0458	0.0180	.758
+98.3	0.282	0.0493	0.0188	.740
+188.3	0.272	0.0537	0.0201	.727
+296.3	0.266	0.0587	0.02195	.711
NOTES:				
These N_{Pr} values not plotted on graph.				
A Source - NBS Compendium, 4.004, @ 100 atmospheres; remaining C_p values from NBS Circular 564 @ 100 atmospheres.				
K and μ values from revised graphs.				

TABLE XVIII

PRANDTL NUMBER OF NITROGEN (continued)

Temperature (°F)	Cp (Btu/#-°F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	N_{Pr}
2000 PSIA				
-193	0.561	0.0975	0.0355	1.54
-148	0.500	0.0542	0.0269	1.01
-103	0.409	0.0481	0.02145	.917
-58	0.360	0.0467	0.0203	.828
-13	0.329	0.0477	0.0201	.781
+32	0.310	0.0491	0.02015	.755
+50	0.303[A]	0.0496	0.02025	.742
+100	0.296[A]	0.0515	0.0206	.740

NOTES:

A Source - Folder 109.141; remaining Cp values from NBS Compendium, 4.004.

μ and K values from revised graphs.

TABLE XIX.

PRANDTL NUMBER OF OXYGEN

Temperature (°F)	Cp (Btu/#-°F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	N_{Pr}
Saturated Liquid				
-351.7	0.3964	1.32	0.1062	4.93
-348.1	0.3962	1.18	0.1051	4.45
-342.7	0.3965	1.03	0.1035	3.96
-333.7	0.398	0.850	0.1007	3.36
-315.7	0.401	0.615	0.0945	2.61
-297.7	0.405	0.463	0.0873	2.15
-260	.....	.....	.....	1.98[A]
-233	0.480[B]	0.260	0.0590	2.115
-216.6	0.570[B]	0.243	0.0511	2.71

NOTES:

A N_{Pr} value taken from Technical Data Book 109.144
B Cp values determined from P-H chart by extrapolation (TDB 101.145 /Rev. 1/).
K Values taken from revised O_2 liquid thermal conductivity graph.
μ Values taken from TDB 103.050 1/2.

Saturated Vapor				
-210	0.419[A]	0.0305	0.01102	1.16
-200	0.523	0.0335	0.01270	1.38
-195	0.603	0.0355	0.01360	1.57

NOTES:

Saturated vapor curve estimated over temperature range, -300 to -210°F.
A Cp values from TDB 105.144.
μ and K values from revised graphs.

TABLE XIX.

PRANDTL NUMBER OF OXYGEN (continued)

Temperature (°F)	Cp (Btu/#-°F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	N_{Pr}
1500 PSIA				
-150	0.827	0.0682	0.0281	2.007
-147.5	0.830	0.0660	0.0273	2.006
-140	0.791	0.0580	0.0256	1.79
-130	0.689	0.0546	0.0230	1.64
-120	0.591	0.0530	0.0217	1.44
-100	0.469	0.0513	0.01995	1.21
-50	0.327	0.0505	0.01794	0.920
0	0.287	0.0518	0.01798	0.827
+50	0.269	0.0544	0.01847	0.792
+125	0.258	0.0584	0.01960	0.769

NOTES:

Cp values from TDB 105.144.
μ and K values from revised graphs.

2000 PSIA				
-130	0.654	0.0750	0.0288	1.70
-125	0.652	0.0720	0.0283	1.66
-120	0.638	0.0696	0.0277	1.60
-110	0.586	0.0661	0.0268	1.44
-75	0.431	0.0595	0.02345	1.09
-50	0.370	0.0595	0.0219	0.971
0	0.314	0.0565	0.02077	0.854
+50	0.288	0.0582	0.0207	0.810

NOTES:

Cp values from Hall and Ibele
μ and K values from revised graphs

TABLE XIX.

PRANDTL NUMBER OF OXYGEN (continued)

Temperature (°F)	Cp (Btu/#-°F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	N_{Pr}
1 Atmosphere				
-225.7	0.220	0.0241	0.00661	0.802
-207.7	0.220	0.0258	0.00720	0.788
-189.7	0.219	0.0276	0.00770	0.785
-153.7	0.219	0.0309	0.00874	0.774
-117.7	0.218	0.0342	0.00980	0.761
-81.7	0.218	0.0373	0.01092	0.745
-45.7	0.218	0.0404	0.01192	0.739
+8.3	0.219	0.0446	0.01338	0.730
+62.3	0.219	0.0487	0.01500	0.711
+116.3	0.220	0.0523	0.01637	0.702
+188.3	0.222	0.0573	0.01828	0.696
+260.3	0.225	0.0620	0.02002	0.697
+296.3	0.226	0.644	0.02088	0.697
(Additional values from NBS Circular 564, p. 426)				
-279.7	.....	.....	.....	0.815
-261.7	.....	.....	.....	0.800
-243.7	.....	.....	.....	0.791
-255.7	.....	.....	.....	0.784
-207.7	.....	.....	.....	0.778
-189.7	.....	.....	.....	0.773
-99.7	.....	.....	.....	0.745
-9.7	.....	.....	.....	0.725
+98.3	.....	.....	.....	0.709

NOTES:

Cp Values from NBS Circular 564, p. 402
K and μ values from revised graphs.

TABLE XIX.

PRANDTL NUMBER OF OXYGEN (continued)

Temperature (°F)	Cp (Btu/#-°F)	μ (#/ft-hr)	K (Btu/ft-hr-°F)	N_{Pr}
200 PSIA				
-210	0.262	0.0275	0.0086	0.838
-150	0.238	0.0333	0.00995	0.797
-100	0.230	0.0367	0.01102	0.766
-50	0.228	0.0404	0.01233	0.747

NOTES:

Cp values from TDB 105.144
μ and K values interpolated from revised graphs.

400 PSIA				
-200	0.396	0.0320	0.01150	1.10
-187.5	0.346	0.0330	0.01125	1.01
-175	0.318	0.0335	0.01090	0.977
-150	0.283	0.0347	0.01085	0.905
-100	0.254	0.0377	0.01170	0.818
-50	0.238	0.0410	0.01280	0.762
0	0.232	0.0446	0.01410	0.734
+50	0.230	0.0482	0.01530	0.725
+125	0.229	0.0533	0.01715	0.712

NOTES:

Cp values from TDB 105.144.
μ and K values interpolated from revised graphs.

TABLE XIX.

PRANDTL NUMBER OF OXYGEN (continued)

Temperature (°F)	Cp (Btu/#-°F)	μ (#/ft-hr)	K (Btu/ft-hr.-°F)	Npr
500 PSIA				
-175	0.442	0.0345	0.01160	1.31
-150	0.315	0.0357	0.01138	0.988
-125	0.286	0.0370	0.01154	0.917
-100	0.269	0.0382	0.01202	0.855
-50	0.248	0.0413	0.01315	0.779
0	0.238	0.0447	0.01430	0.744
+50	0.234	0.0482	0.01547	0.729
+100	0.234	0.0517	0.01670	0.724
+125	0.236	0.0535	0.01732	0.728

NOTES:

Cp values from TDB 105.144.
μ and K values from revised graphs.

1000 PSIA				
-150	0.745	0.0447	0.01875	1.78
-140	0.559	0.0437	0.01720	1.42
-130	0.463	0.0431	0.01620	1.23
-120	0.407	0.0426	0.01538	1.12
-100	0.348	0.0425	0.01490	0.993
-50	0.289	0.0444	0.01523	0.843
0	0.267	0.0475	0.01606	0.790
+50	0.255	0.0506	0.01697	0.760
+125	0.250	0.0552	0.01850	0.746

NOTES:

Cp values from TDB 105.144
μ and K values from revised graphs.

AIR PRODUCTS and CHEMICALS, Inc., P. O. Box 538, Allentown, Pennsylvania ASD-TR-61-625. THERMODYNAMIC DATA on OXYGEN AND NITROGEN. Final Report. September 1961. 151 Pages (incl. Figures and Tables). 239 References. Unclassified Report The following data, which were compiled from published literature, are presented graphically as a function of temperature and pressure: Viscosity of Nitrogen, Viscosity of Oxygen, Viscosity of Air, Viscosity of Saturated Liquid (Oxygen, Nitrogen, and Mixtures), Over	UNCLASSIFIED Thermodynamic Data Survey I. Project 1-(1-3048) Task 304802 II. AF 33(616)-6287 III. AIR PRODUCTS and CHEMICALS, Inc. Allentown, Pa. IV. Jerome Brewer V. ASD-TR-61-625 VI. Available from OTS VII. In ASTIA Collection UNCLASSIFIED
Vapor-Liquid Equilibrium Ratios: Oxygen-Nitrogen System, Dew Points: Oxygen-Nitrogen System, Bubble Points: Oxygen-Nitrogen System, Thermal Conductivity of Nitrogen, Thermal Conductivity of Oxygen, Thermal Conductivity of Saturated Liquefied Nitrogen and Oxygen, Density of Oxygen, Density of Nitrogen, Prandtl Number of Nitrogen, and Prandtl Number of Oxygen. For each of the above properties a discussion of their critical evaluation was made. Two complete sets of curves were presented, one set with experimental and correlative data points and one set without data points. A complete bibliography of the sources used Continued	UNCLASSIFIED Thermodynamic Data Survey UNCLASSIFIED

for each property are given as well as a master bibliography which include all sources consulted or related to the subject. Tables of tabulated values of the properties used to construct the various graphs are presented.	UNCLASSIFIED Thermodynamic Data Survey UNCLASSIFIED

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Vapor-Liquid Equilibrium Ratios: Oxygen-Nitrogen System, Dew Points: Oxygen-Nitrogen System, Bubble Points: Oxygen-Nitrogen System, Thermal Conductivity of Nitrogen, Thermal Conductivity of Oxygen, Thermal Conductivity of Saturated Liquefied Nitrogen and Oxygen, Density of Oxygen, Density of Nitrogen, Prandtl Number of Nitrogen, and Prandtl Number of Oxygen. For each of the above properties a discussion of their critical evaluation was made. Two complete sets of curves were presented, one set with experimental and correlative data points and one set without data points. A complete bibliography of the sources used Continued	UNCLASSIFIED Oxygen-Nitrogen UNCLASSIFIED

for each property are given as well as a master bibliography which include all sources consulted or related to the subject. Tables of tabulated values of the properties used to construct the various graphs are presented.	UNCLASSIFIED Oxygen-Nitrogen

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Mixtures), Vapor-Liquid Equilibrium Ratios: Oxygen-Nitrogen System, Dew Points: Oxygen-Nitrogen System, Bubble Points: Oxygen-Nitrogen System, Thermal Conductivity of Nitrogen, Thermal Conductivity of Oxygen, Thermal Conductivity of Saturated Liquefied Nitrogen and Oxygen, Density of Oxygen, Density of Nitrogen, Prandtl Number of Nitrogen, and Prandtl Number of Oxygen. For each of the above properties a discussion of their critical evaluation was made. Two complete sets of cruves were presented, one set with experimental and correlative data points and one set without data Continued	UNCLASSIFIED Heat Transfer UNCLASSIFIED

points. A complete bibliography of the sources used for each property are given as well as a master bibliography which include all sources consulted or related to the subject. Tables of tabulated values of the properties used to construct the various graphs are presented.	UNCLASSIFIED Heat Transfer